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Flexible 3-Dimension Measuring System Using Robot Hand

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Abstract

A robotic system with a 3-dimensional profile measuring sensor is developed in order to measure the complicated shape of the target body. Due to this 3-dimensional profile measuring sensor, a computer is able to adjust the posture of the robot hand so that complicated global profile of the target body can be recognized after several measurements from the variant directions. In order to enable fast data processing, a digital signal processor and a look-up table is introduced

KEY WORDS : 3-dimensional measuring, vision sensor, image processing, robot hand

1. Introduction

A flexible robot systems with intelligent vision capability has been recognized as vital to the success of flexible manufacturing systems.[1)~10)] In this paper, we present an industrial robotic system that has a function to measure complicated 3-dimensional shape of the target body.

A 3-dimensional profile measurement sensor based on the slit-ray projection method is installed on the tip of the robot hand in order to measure the target body which has complicated 3-dimensional shape. Owing to the flexibility of posture of the robot hand, measurements from the variant directions can be executed. Postures of the robot hand are controlled by the computer considering the information obtained by the 3-dimensional shape measurement sensor.

The 3-dimensional profile data obtained from variant directions are combined to give the essentional information about the global profile of the target body. One feature of our system is rapid sampling speed and compactness of our 3-dimensional profile measurement sensor. Our 3-dimensional profile measurement sensor consists of a semiconductor laser tube(3mW), one galvanometric

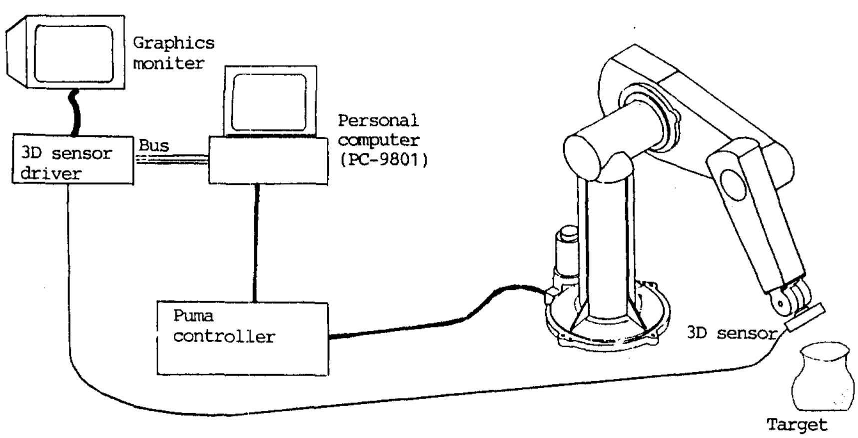

Fig.1 System configration

mirror to project the laser slit-ray in the specified direction and one TV-camera to detect slit-ray images. A video signal processing unit is employed in order to reduce the amount of image data to be processed and enable a fast sampling. The real-time video processing unit enables real-time measurement of raster coordinates of the slit-ray images. Furthermore, all the calculations to transform raster coordinates to world coordinates can be removed, since all calculation procedures can be incorporated into a look-up table. Due to the employment of DSP(Digitral Signal Processor : TMS320 c25) and look-up table, 3-dimensional positional data of more than 10000 target points can be obtained in one second. In order to see applicability of our system, some experiments are performed. Unimate PUMA 560 robot with 3-dimensional shape measurement sensor and a 16-bit computer(NEC PC-9801VX) have been employed to evaluate the performance of our techniques. Experimental results obtained are satisfactory.

2. Overall system configration

The overall system configration used in the experiments is shown in Fig.1. The major compoments include a PUMA560 robot, a 3-dimensional measuring sensor, an image processing unit, and a 16-bit personal computer. The 16-bit personal computer serves as a super visory computer for the PUMA controller and the image processing unit.

The posture of the 3-dimensional sensor are controlled via the PUMA so that the gloval profile of the target body with a complex surround shape can be obtained with accurary.

3. 3-dimensional measuring sensor

Compact 3-dimensioal measuring sensor is composed of a small TV-camera, A semiconductor laser tube and a scanning mirror(see Fig.2). a laser-beam emitted from a semiconductor laser tube is expanded to be a laser slit-ray via a cylindrical lens. The laser slit-ray is controlled to project over the target body to realize the laser slit-ray projection method. The scanning mirror is drived syncronously with the veritcal scanning signals of the TV-camera.

The image signals of the slit-ray are transfered to the video signal processing unit in the 3-dimensional sensor driver, which gives the 3-dimensional world coordinates(x,y,z) of the sample points.

Functions of image processing unit are obtaining the raster coordinates(u,v) of the sample points, transforming the raster coordinates(u,v) into the 3-dimensional sensor coordinates(x,y,z), and giving the 3-dimensional world coordinate considering the posture of the robot hand (see Fig.3).

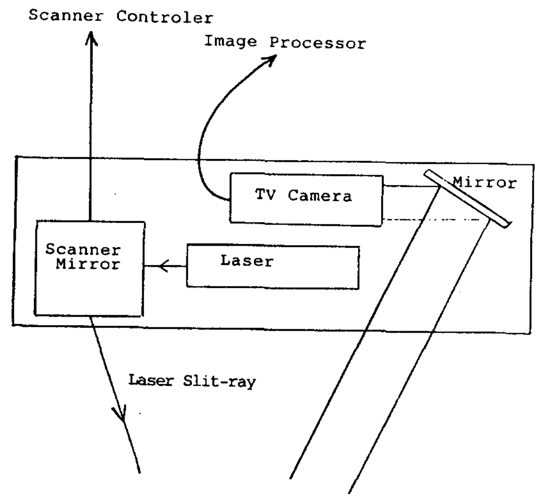

Fig.2 3D sensor

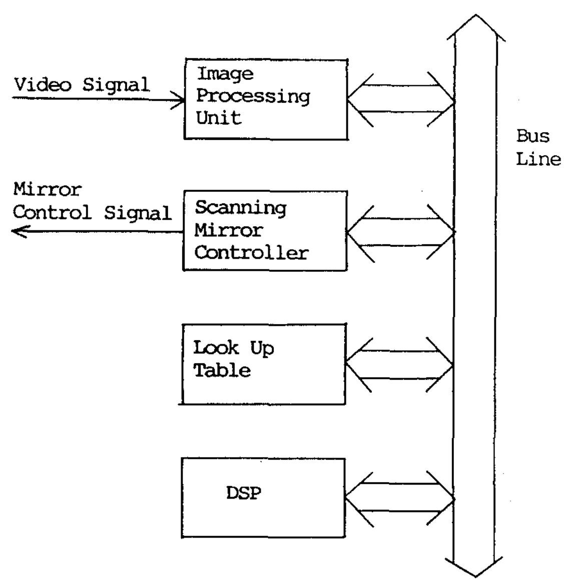

Fig.3 3D sensor dirver

The raster coordinates(u,v) of the target can be easily obtained by a simple hardware as shown in Fig .4.
This hardware digitized the video signal to one bit with 256*256 pixels per a frame. Since binary slit-ray image sampled is usually broader than desirable, a horizontal thinning operation is given to obtain the raster coordinates of the centerline. Therefore, it is preferable to settle the TV-camera so that the horizontal scanning line of the TV-camera perpendicularly intersects the slit-ray image.

While transformation of the raster coordinates(u, v) into the 3-dimensional sensor coordinates(x,y,z) is rather simple, some tactful technique is necessary in order to process a large number of image data in a short period.

look-up table technique is employed so that even a conventional 16-bit personal computer can acomplish this transformation. Also correction of aberration caused by the TV-camera lens can be incorporated into this look-up table.

In order to transform the sensor coordinates into the world coordinates, postures of the 3-dimensional measuring sensor or the robot hand needs to be measured with accuracy. Since all the information about posture of the robot hand can be obtained via the PUMA controller, one digital signal processor is employed to execute this transformation. Fig.3 shows the block diagram of these units.

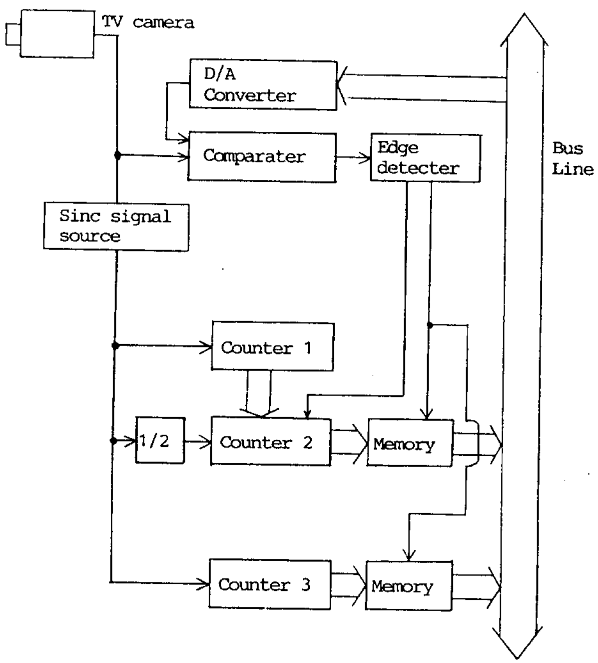

Fig.4 Image processing unit

4. Determination of 3-dimensional coordinates

Determination of sensor coordinate

Before determining the 3-dimensional position of target points by means of trigonometry, the calibration of the TV-camera and the slit-ray projection is necessary. In our system, the sensor coordinate system which employs the cylindrical coordinates(r,θ,z) is fixed on the 3-dimensional sensor, so that z axis concides with the rotating axis of the scanning mirror.

The relation between the raster coordinate system (u,v) and the sensor coordinate system is expressed by

$$\lambda\begin{pmatrix} u \\ v \\ 1 \end{pmatrix} = \begin{pmatrix} h_{11}\cos\theta + h_{12}\sin\theta & h_{13} & h_{14} \\ h_{21}\cos\theta + h_{22}\sin\theta & h_{23} & h_{24} \\ h_{31}\cos\theta + h_{32}\sin\theta & h_{33} & 1 \end{pmatrix} \begin{pmatrix} r \\ z \\ 1 \end{pmatrix} \quad (1)$$

where h_{ij} represents the geometrical arrangement of the TV-camera and the slit-ray.

Based on a minimum squared error technique, six distinguished noncoplanar points whose sensor coordinates are already known are measured to determine the value h_{ij}.

Once parameters h_{ij} in Eq.(1) are determined, elimination of λ yields

$$r = f_1(u,v,\theta)$$
$$z = f_2(u,v,\theta) \quad (2)$$

where f_1, f_2 are abbreviated forms. Eqs.(2) transform the raster coordinate to the sensor coordinate.

While all the calculations in Eqs.(2) can be incorporated into a look-up table, introduction of a look-up table to transform (u,v) to (r,θ,z) is sometimes not preferable.

Consider the case that the resolution of the rotating angle of the scanning mirror is high. The table might spend so much memories. In such a case, transformation of Eqs.(2) is executed with the digital signal processor. In other cases, the look-up table is employed.

Determination of the world coordinate

Once the sensor coordinates(r,θ,z) of the target points are obtained, they have to be transformed into the world coordinates(x,y,z), considering the posture and the position of the robot hand.

The transformation can be easily performed by the well-known homogeneous equation

$$\begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix} = C \begin{pmatrix} r\cos\theta \\ r\sin\theta \\ z \\ 1 \end{pmatrix} \tag{3}$$

where the coefficient matrix C is determined by the posture and the position of the robot hand.

5. Measuring procedures

Fig.5 shows the flow chart of a measuring procesure of our system.

At the beginning, the robot hand is moved over the measuring bench until the 3-dimensional measuring sensor detects the target body in the sight. During this detecting step, the resolution of the 3-dimensional sensor is adjusted low enough to detect the target body, so that data processing speed becomes faster

Once the target is detected, pan and tilt angles of the target surface 'are calculated in order to determine the tangent planes.

Considering the tangent planes of the target surface, the computer determines the next posture of the 3-dimensional sensor so that the next measurement gives much informations about the target body. According to the above results, the robot

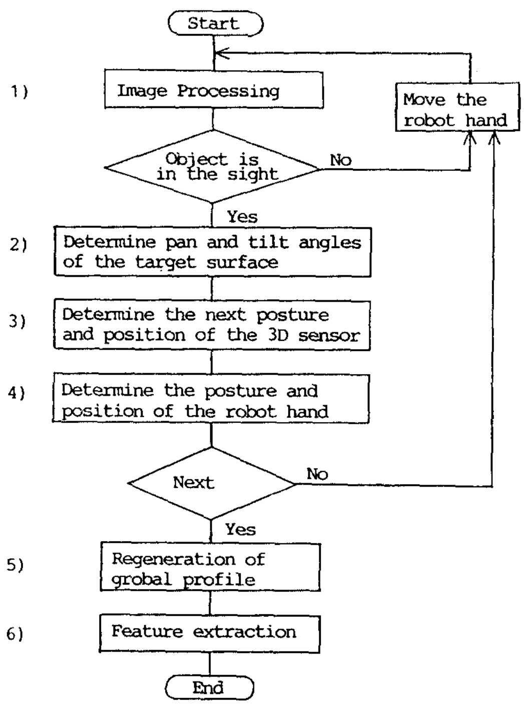

Fig.5 Flow chart

hand is controlled. The spatial distance from the target object and the 3-dimensional sensor is adjusted to be in a prefixed range.

The above procedures are repeated until all the surronding surfaces of the target object are measured. Once all the informations about the gloval profile of the target are obtained, a feature extraction program starts. This program extracts the flat surfaces of the target object. If target objects are limited to polyhedrons, the shape and position of all the surface planes can be obtained easily.

6. Experimental result

An experiment was conducted to evaluate the performance of the measuring system.

Photo.1 shows experimental systems, where one target object can be seen on the measuring table. The target object is a typical japanese doll "Dharma". During the measurement, the spatial distance from the target doll to the 3-dimensional sensor was adjusted to be about fifteen milimeters.

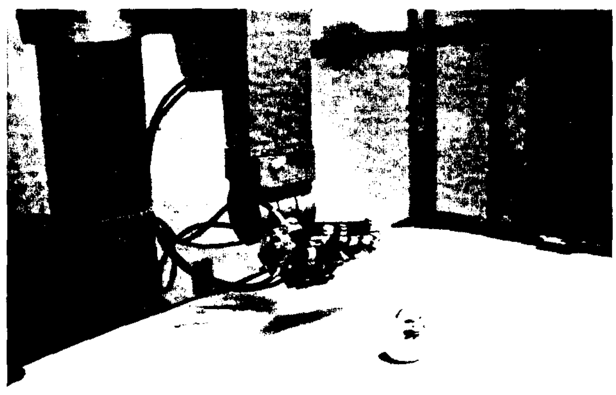

photo.1 Experimental system

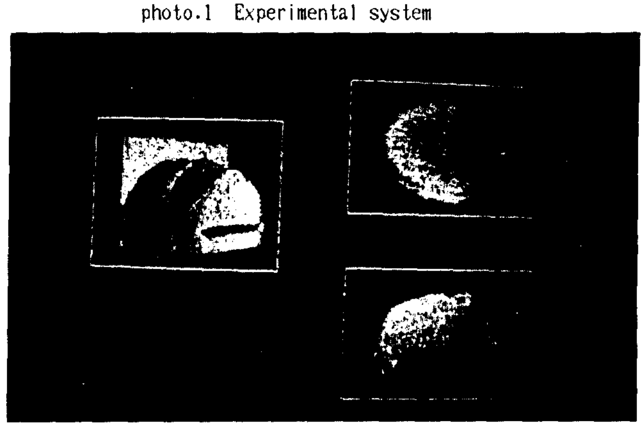

photo.2 Experimental result

The measurement of this doll was executed automatically in the eight difference directions.

Photo.2 shows the experimental result, where the target doll is regenerated by plotting the sampled points on the TV display. While the 3-dimensional sensor itself has measuring errors less than 0.5 mm, the maximum measuring errors of the total system became 2.0 mm. This error might be caused by the elasticity of the robot hand. In order to enhance the accuracy of the total system, the compensation of this unfavourable elasticity is necessary using some auxiliary sensors or calibrating the distortion of the robot arm.

7. Conclusion

An industrial robotic system to measure complicated 3-dimensional shape of the target object is developed. On the tip of the robot hand, a 3-dimensional profile measurement sensor based on the slit-ray projection method is installed. Owing to the flexibility of the posture of the robot hand, measurements in the variant directions become possible. Postures of the robot hand are controlled according to the information obtained by the 3-dimensional measuring sensor.

One experimental result demonstrate that the system can operate with the expected performance. Since the image processing unit introduced in our system treats only binary signals, the image processing of grey scale signals is preferrable in order to be robust in an hazardous enoironment as would be found in a real world application.

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