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Acquiring 3-Dimensional Data of a Human Face Using a Laser Slit-Ray Projection Method

T.Ishimatsu*, N.Taguchi**, K.Kawasue** and K.Kumon*

*Department of Mechanical Engineering
Nagasaki University

**Graduate Student
Department of Mechanical Engineering
Nagasaki University

Abstract

This paper describes a system which enables a fast 3-dimensional measurement of a human face using a sli-ray projection method. One distinctive feature of our system is that a real-time video signal processor is employed in order to reduce the amount of image data to be processed and enable a fast measurement. Another feature of our system is that a skillful calibration software is developed. Due to this calibration software, operators can be free from cumbersome settings of the measuring system.

* Department of Mechanical Engineering
Nagasaki University
Bunkyo-machi,
Nagasaki
Japan 852

1. Introduction

3-dimensional informations about a human body ,a human face and a human head are very important in many fields, like clothing planning ,orthopedics surgery dental surgery and human engineering. Moire topography is a well-known powerful method to enable such non-contact measurements with excellent reproducibility.[1] While Moire topography gives a contour map, or Moire fringe pattern of target objects, a complicated image analysis of the contour map is indispensable in order to obtain numerical 3-dimensional surface data. Therefore,the computer employed needs to be highly efficient. Furthermore, it is important to note that the obtained numerical 3-dimensional data are relative values and not absolute values.

Some other methods have been developed to obtain 3-dimensional information about target objects. One is based on the stereometric technique with two TV cameras. While the stereometric technique has an advantage that the 3-dimensional data can be obtained from two video images, the computational complexity to find sets of corresponding points between the two video images remains.[4]

A laser slit-ray projection method has a distinctive advantage over the methods mentioned above,that numerical data of the 3-dimensaional target surface can be obtained unambigously with more simple image analysis. However, since a slit-ray projection method gives 3-dimensional data of multiple points only on the slit-ray, scanning operation of the slit-ray across the target surface is necessary to measure the overall surface. Therefore, sometimes analysis of hundreds of video images and a few minutes of data-operation are requred. Improvement of these operation is indispensable in order to apply slit-ray projection method to practical uses ,where the analysis of images should be finished in a few seconds.[2)~7)]

This paper discribes a system which enables a fast 3-dimensional measurement of a human face using a slit-ray projection method. The system developed in this study consists of a laser slit-ray projector, two CCD TV cameras, a real-time video signal processor and a 16-bit computer to control the total system and to perform data-processings.

One distinctive feature of this system developed is that a real-time video signal processor is employed in order to reduce the amount of image data to be processed and enable fast measurements. Another feature of this system is that two TV cameras are employed in order to eliminate un-measureable portions of the human face.

A calibration method is also presented here. Only by sampling some base points whose 3-dimensional coordinates are already known,the calibration of the measuring system can be achieved. Due to this calibration method , operators can be free from cumbersome settings of the TV cameras and the slit-ray projector.

The first part of this paper describes a system whereby the 3-dimensional information about a human face can be obtained, and explains a real-time video signal processor to extract the useful information. The second part shows how the calibration and the measurement are achieved. Furthermore, the experimental results are shown.

2. Measuring System

The setup of the 3-dimensional profile measuring system of a human face developed here is shown in Fig.1. A laser slit-ray is projected on the human face from the tip of the arm. The slit-ray is generated from a laser beam (2 mW) through a rod lens. Two CCD TV cameras are mounted on the arm. These cameras sample the reflected light of the slit-ray projected on the human face. The video signals of these cameras are alternatively sampled and converted into binary signals by a real-time video signal processor. Since the binary slit-ray images, detected by the TV cameras, are usually broader than desirable, a horizontal thinning operation is given to obtain the raster coordinates of the center line. Each set of raster coordinates of the centerline extracted from every frame data are stored on a temporary memory. In order to obtain gloval profile of the human face, the arm is rotated by a controlled motor with arbitrary fixed rotating speed. After obtaining all the data about the slit-ray images , a digital signal processor(DSP : TE TMS320C25) caluculates the 3-dimensional coordinates of the every points on the human face and a 16-bit computer (NEC PC9801VX) displays the results graphically.

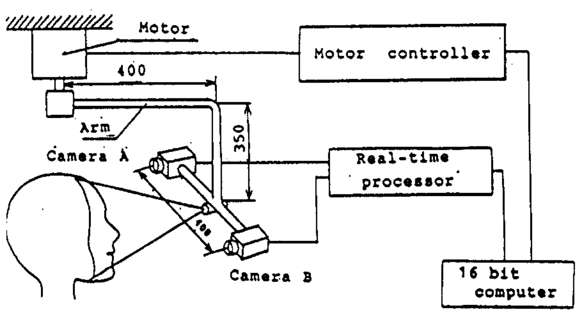


Fig.1 System configuration

3. Real-time video processor

Our system developed employed a real-time video signal processor, which extracts the important information from the video signals and reduces the amount of image data to be processed. Owing to this real-time video processor, fast sampling and effective usage of memory become possible. Two CCD cameras employed are synchronized with external signals supplied by the external syncronous signal source. The video signals of these cameras are processed alternatively by the real time video processor.

First, this real-time video processor digitizes the video signal to one bit with 256x256 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 of the slit-ray image. Therefore, it is preferable to settle the TV cameras so that the horizontal scanning line of the TV cameras perpendicularly intersects the slit-ray image.

A block diagram of the real-time video processor is shown in Fig.2. A timing chart of this processor is also shown in Fig.3, where the signals during the period of the m-th horizontal scanning are shown. When the rise of binary video signal is detected (at P1 in Fig.2), Edge detector activates Edge signal + and the raster coordinate n1 is preset into Counter 1. Moreover, when the fall of binary video signal is detected (at P2 in Fig.2) Edge detector activates Edge signal - and the data in Counter 2 and Counter 3 is stored in the temporary memory.

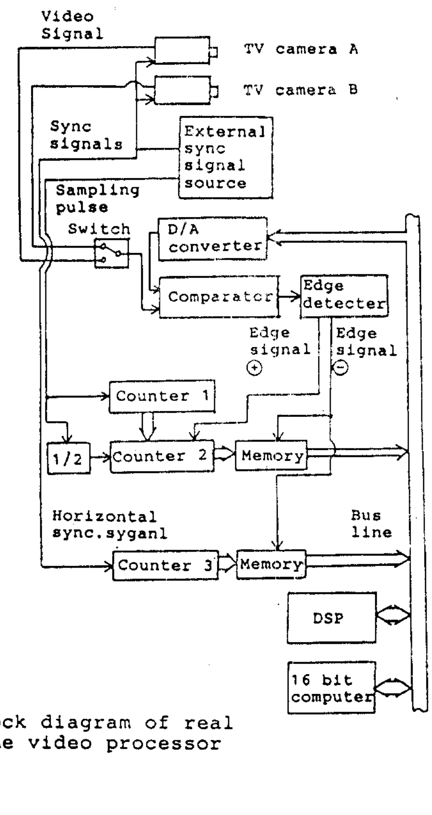


Fig.2 Block diagram of real time video processor

Since incrementing speed of Counter 2 is reduced to half by the frequency divider, output data of Counter 2 becomes (n1+n2)/2 which corresponds to the horizontal raster coordinate of the midpoint of P1 and P2. Output data of Counter 3 is the vertical raster coordinate m. Just after one vertical scanning on one TV camera has finished, all data stored in the temporary memory are transfered to a DSP(digital signal prcessor). The DSP converts raster coordinates of target points to 3-dimensional world coordinates.

One example of slit image

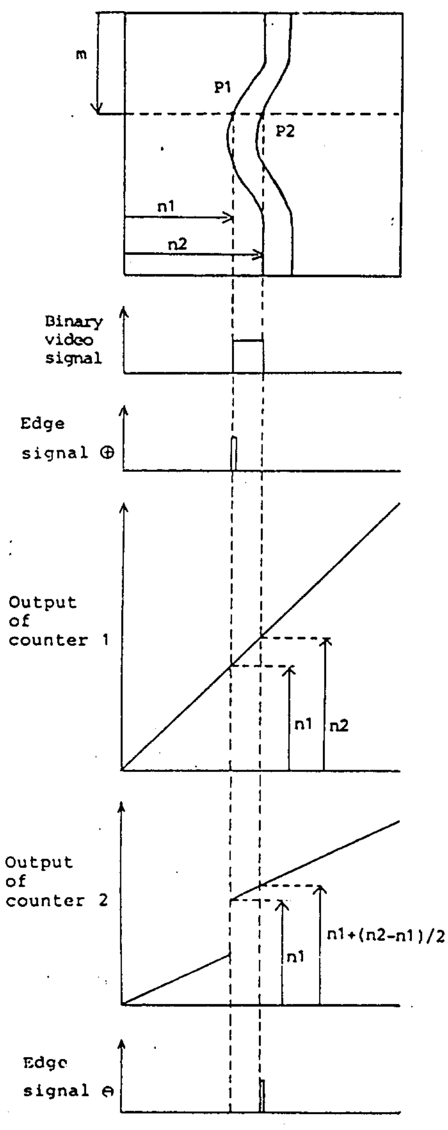


Fig.3 Timing chart

4. Calibration Method

Before measuring the 3-dimensional profile of a human face, calibrations to establish the 3-dimensional geometric relation between the TV cameras and the laser slit-ray projector are necessary. Furthermore,the calibration of the rotating axis of the arm is also necessary.

4.1 TV cameras and slit-ray projector

Calibrations of TV cameras and slit-ray projector can be achieved by sampling four base points whose world coordinates are known in advance.

Suppose the world coordinate system is fixed on the measuring bench, X-axis and the Y-axis on the bench, the Z-axis, extending perpendicularly upward.

The relationship between 3-dimensional points in the world coordinate system and the corresponding 2-dimensional points in the raster coordinate system is essentially a perspective transformation. Let the world coordinates of the object point be x , y , z and cooresponding raster coordinates be u ,v . Then the following equation is satisfied,

$$\lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} h11 & h12 & h13 & h14 \\ h21 & h22 & h23 & h24 \\ h31 & h32 & h33 & h34 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \quad (1)$$

where the elements hij represent the relationship between the two coordinates.

It is well-known that based on the minimum squared error technique these hij can be determined by sampling six distinguished noncoplanar points , whose world coordinates are already known, with the TV cameras . Following this procedure, after the calibration of the TV cameras, the laser slit-ray projector has to be calibrated in the next step. This calibration of the slit-ray projector can incorporate with that of the cameras as follows.

Since the slit-ray plane is expressed by the fóllowing quation,

$$a_1 x + a_2 y + a_3 z + a_4 = 0 \quad (2)$$

Eq.(1) and Eq.(2) can be expressed as the following one matrix equation.

$$\lambda \begin{bmatrix} u \\ v \\ 1 \\ 0 \end{bmatrix} = \begin{bmatrix} h11 & h12 & h13 & h14 \\ h21 & h22 & h23 & h24 \\ h31 & h32 & h33 & 1 \\ a1 & a2 & a3 & a4 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

Inverting the above coefficient matrix yields the following general equation form for the slit-ray projection method .

$$\xi \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} m11 & m12 & m13 \\ m21 & m22 & m23 \\ m31 & m32 & m33 \\ m41 & m42 & 1 \end{bmatrix} \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \quad (4)$$

where coefficents mij represent the configurations of the TV cameras and the laser slit-ray.

Using the above equatiom which represents the relation between the world coordinates x,y,z and the raster coordinates u,v instead of Eq.(1), coefficients mij can be determined by the following procedure. Let the world coordinates of the distinguished four points which are on the slit-ray plane be xi,yi,zi (i=1,,4) and corresponding raster coordinates ui,vi. Rearranging Eq.(4) yields

$$T\,m = w \tag{5}$$

where

$$T=\begin{bmatrix} u1 & v1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & -u1x1 & -v1x1 \\ 0 & 0 & 0 & u1 & v1 & 1 & 0 & 0 & 0 & -u1y1 & -v1y1 \\ 0 & 0 & 0 & 0 & 0 & 0 & u1 & v1 & 1 & -u1z1 & -v1z1 \\ u2 & v2 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & -u2x2 & -v2x2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & & \vdots & \\ 0 & 0 & 0 & 0 & 0 & 0 & u4 & v4 & 1 & -u4z4 & -v4z4 \end{bmatrix}$$

$$m=\begin{bmatrix} m11 \\ m12 \\ m13 \\ m21 \\ \vdots \\ m42 \end{bmatrix}, \quad w=\begin{bmatrix} x1 \\ y1 \\ z1 \\ x2 \\ \vdots \\ z4 \end{bmatrix}$$

Since the coefficient matrix T and the vector m in Eq.(5) is determined by the world coordinates and the corresponding raster coordinates of the four distinguished points, it can be shown that the solution of Eq.(5) is

$$m=(T^{T}T)^{-1}T^{T}w \tag{6}$$

where the matrix $(T^{T}T)^{-1}T^{T}$ is the pseud inverse of the matrix T.

The calibration is achieved as follows. First, four points on the slit-ray plane are selected and their world coordinates are manually measured . Next the raster coordinates of the selected points are measured by the TV cameras and the real-time video processor. After that, all the parameters are calculated by Eq.(6).

4.2 Rotating axis

It is important to note that the above calibration of the TV cameras and the slit-ray projector have to be executed under the condition that the rotating arm is fixed to a specified angle. Since the TV cameras and the slit-ray projector are mounted on the rotating arm, the 3-dimensional data calculated by Eq.(4) have to be modified considering the effects of the rotation. In order to calculate the effects of the rotation of the arm the rotating axis needs to be calibrated with accuracy. The calibration of the rotating axis can be achieved by rotating the arm and sampling three points whose 3-dimensional coordinates are known in advance.

Suppose the rotating axis intersects the origin of the world coordinate as is depicted in Fig.4 (a), where ψ , ϕ are deflected angle and θ is rotating angle. When rotating angle is θ ,the relation between the world coordinates X,Y,Z and the rotating coordinates $x(\theta),y(\theta),z(\theta)$ becomes

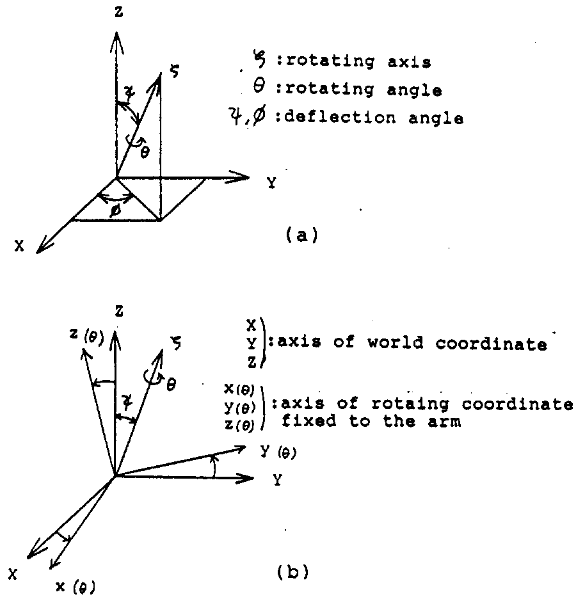


Fig.4 Coordinate of System

$$\begin{bmatrix} \cos\psi\cos\phi & \cos\psi\sin\phi & -\sin\psi \\ -\sin\phi & \cos\phi & 0 \\ \sin\psi\cos\phi & \sin\psi\sin\phi & \cos\psi \end{bmatrix}\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

$$=\begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\times\begin{bmatrix} \cos\psi\cos\phi & \cos\psi\sin\phi & -\sin\psi \\ -\sin\phi & \cos\phi & 0 \\ \sin\psi\cos\phi & \sin\psi\sin\phi & \cos\psi \end{bmatrix}\begin{bmatrix} x(\theta) \\ y(\theta) \\ z(\theta) \end{bmatrix} \tag{7}$$

Introducing new variables,this equation becomes the following equation

$$\begin{bmatrix} c11 & c12 & c13 \\ c21 & c22 & 0 \\ c31 & c32 & c33 \end{bmatrix}\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

$$=\begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} c11 & c12 & c13 \\ c21 & c22 & 0 \\ c31 & c32 & c33 \end{bmatrix}\begin{bmatrix} x(\theta) \\ y(\theta) \\ z(\theta) \end{bmatrix}$$

where
$$c11^2 + c12^2 + c13^2 = 1$$
$$c21^2 + c22^2 = 1$$
$$c31^2 + c32^2 + c33^2 = 1$$

Considering that $c11 \fallingdotseq 1$ and $c33 \fallingdotseq 1$,we obtain the following equation which is equivalent to the above equation

$$
\begin{bmatrix} 1 & d12 & d13 \\ d21 & d22 & 0 \\ d31 & d32 & 1 \end{bmatrix}
\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}
= \begin{bmatrix} \cos & \sin & 0 \\ \sin & \cos & 0 \\ 0 & 0 & 1 \end{bmatrix}
\begin{bmatrix} 1 & d12 & d13 \\ d21 & d22 & 0 \\ d31 & d32 & 1 \end{bmatrix}
\begin{bmatrix} x(\theta) \\ Y(\theta) \\ Z(\theta) \end{bmatrix}
$$

where

$$
\begin{aligned}
d1i &= c1i/e11 \\
d2i &= c2i \\
d3i &= c3i/e33 \qquad (8) \\
e11^2 &= c11^2 + c12^2 + c13^2 \\
e33^2 &= c31^2 + c32^2 + c33^2
\end{aligned}
$$

Rearranging the above equation, we obtain

$$
\begin{bmatrix}
y\cos\theta - Y & z\cos\theta - Z & x\sin\theta & y\sin\theta & 0 & 0 \\
-y\sin\theta & -z\sin\theta & x\cos\theta - X & y\cos\theta - Y & 0 & 0 \\
0 & 0 & 0 & 0 & x-X & y-Y
\end{bmatrix}
\times
\begin{bmatrix} d12 \\ d13 \\ d21 \\ d22 \\ d31 \\ d32 \end{bmatrix}
=
\begin{bmatrix} X - x\cos\theta \\ x\sin\theta \\ Z - z \end{bmatrix}
\qquad (9)
$$

Eq.(9) is valid for any rotating angle. Therefore, sampling at three diffrent rotating angle θ_1 , θ_2 and θ_3 gives

$$
\begin{bmatrix}
y_1\cos\theta_1 - Y_1 & z_1\cos\theta_1 - Z_1 & x_1\sin\theta_1 & y_1\sin\theta_1 & 0 & 0 \\
-y_1\sin\theta_1 & -z_1\sin\theta_1 & x_1\cos\theta_1 - X_1 & y_1\cos\theta_1 - Y_1 & 0 & 0 \\
0 & 0 & 0 & 0 & x_1 - X_1 & y_1 - Y_1 \\
y_2\cos\theta_2 - Y & z_2\cos\theta_2 - Z_2 & x_2\sin\theta_2 & y_2\sin\theta_2 & 0 & 0 \\
-y_2\sin\theta_2 & -z_2\sin\theta_2 & x_2\cos\theta_2 - X_2 & y_2\cos\theta_2 - Y_2 & 0 & 0 \\
0 & 0 & 0 & 0 & x_2 - X_2 & y_2 - Y_2 \\
y_3\cos\theta_3 - Y_3 & z_3\cos\theta_3 - Z_3 & x_3\sin\theta_3 & y_3\sin\theta_3 & 0 & 0 \\
-y_3\sin\theta_3 & -z_3\sin\theta_3 & x_3\cos\theta_3 - X_3 & y_3\cos\theta_3 - Y_3 & 0 & 0 \\
0 & 0 & 0 & 0 & x_3 - X_3 & y_3 - Y_3
\end{bmatrix}
\begin{bmatrix} d12 \\ d13 \\ d21 \\ d22 \\ d31 \\ d32 \end{bmatrix}
=
\begin{bmatrix} X_1 - x_1\cos\theta_1 \\ x_1\sin\theta_1 \\ Z_1 - z_1 \\ X_2 - x_2\cos\theta_2 \\ x_2\sin\theta_2 \\ Z_2 - z_2 \\ X_3 - x_3\cos\theta_3 \\ x_3\sin\theta_3 \\ Z_3 - z_3 \end{bmatrix}
$$

where Xi,Yi,Zi are the world coordinates of the i-th sampling points and xi,yi,zi are the corresponding rotating coordinates measured.

The coeficient matrix and right-hand side term of the above equation can be determined by rotating the arm and sampling three points whose world coordinates are known . Therefore, unknown variables dij are determined using the pseud inverse matrix.

Once variables dij are determined, variables cij can be also determined by the relation of Eq.(8).

Inverting coefficient matrix in the left hand side term of Eq.(7) ,we obtain the equation to convert rotating coordinates $x(\theta)$, $y(\theta)$, $z(\theta)$ to the world coordinates X,Y,Z

$$
\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}
= \left\{ (\cos\theta - 1)
\begin{bmatrix} 1 - c31^2 & -c31\cdot c32 & c11\cdot c13 \\ -c31\cdot c32 & 1 - c32^2 & c12\cdot c13 \\ c11\cdot c13 & c12\cdot c13 & c13^2 \end{bmatrix}
+ \sin\theta \begin{bmatrix} 0 & c33 & c32 \\ c33 & 0 & c31 \\ c32 & c31 & 0 \end{bmatrix}
+ \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \right\}
\begin{bmatrix} x(\theta) \\ y(\theta) \\ z(\theta) \end{bmatrix}
$$

where cij are determined by the above calibration.

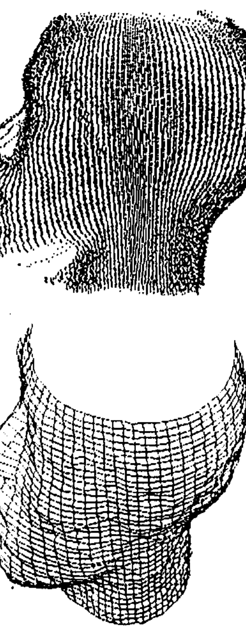
5. Experimental Results

In order to test the utility of our system developed, one experimental measurement is performed.

Fig.5 shows one experimental result, where the target person wears a white cap so that his actual head surface can be measured. Here 240 frame data are processed and 3-dimensional coordinates of totally 46000 points around the human head are measured in 8.0 second. In Fig.5(a) all the data measured are plotted. In Fig.5(b) the head of target person is regenerated in order to show the accuracy of our system.

Each raster coordinate ui and vi of the sampled points is stored as a 8-bit data in our sistem. This means that 100 K-byte memories are sufficient to store all the 3-dimensional information of the human head in this case.

Analysis indicates that the maximum absolute error in position measured by our system here is not greater than 2.0 milimeters.



(a)

(b)

Fig.5 Experimental results

6. Conclusions

A system which enables a fast 3-dimensional profile mesurement of a human face using a slit-ray projection method is developed. Due to an employment of a real-time video signal processor, the extraction of the necessary information from the video signal is performed quickly, and the reduction of the amount of image data to be processed become possible. Experimental results shows that the method of calibrating the TV camera and the slit-ray projector used in our system is convenient and sufficiently accurate.

References

1)S.Inoue, et al.:Moire topography,Orthopedics Surgery (in Japanese),28-7,746/754(1977)

2)Y.Shirai:Recognition of polyhedrons with a range finder, Pattern Recognition, 4, 243/250(1972)

3)G.J.Agin and T.O.Binford:Computer Description of Curved Objects, IEEE on Computers, C-25-4, 439/449(1976)

4)C.K.Wu and D.Q.Wang : Acquiring 3-D Spatial Data of a Real Object, CVGIP, 28, 126/133(1984)

5)T.Agui, et al.: 3-D Object Data Input System Using Real-View Mirrors,Trans. IE., ICE. (in Japanese), J70-D5, 995/1002(1987)

6)H. Naruse, et al.:High Accuracy Distance and Attitude Measurement Using Slit-Ray Projection Method,Trans. IE., ICE. (in Japanese), J69 - D12, 1888/1894 (1986)

7)O.Ozeki, et al.: Real Time Range Measurement System Using Slit-Ray Projection, Trans. IE., ICE.(in Japanese), J68-D5,1141/1148(1985)