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An Approach for Real-Time 3-Dimensional Shape Measurement of Human Head

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Abstract

This paper describes a system which enables a fast 3-dimensional measuring of a human head using a slit-ray projection method . One feature of our system is that almost all calculations are executed using a look-up table , so that , forty thousands of sample point scan be processed in a few seconds . The feasibility of our system for practical applications is demonstrated measuring a human head .

1. Introduction

Rapid and accurate 3-dimensional shape measurement is highly desirable for realizing a stable computer vision for practical use in the field of mechanical engineering and also bio-medical engineering.

Noncontact 3-dimensional shape mesurements are divided into two categorys.[1)~3)] One , refered to as passive , is based on finding the corresponding pixel pair in two images. The other is an active range finder or light projection method which uses a spot- or slit-light projector and a video camera to pick up the illuminated sceane.

Concerning to the active range finder, there are some problems. One problem is that image data acquisition time may be long because the projected spot or line is scanned across the object to provide range data over the entire sceane and the measurement rate is limited by the TV frame rate of the camera.[8)]

Another problem occures because of the great amount of image data. While real-time measurement is desirable , operating speed of the computer is not fast enough to operate the image data simultaneously. Therefore,some methods to employ DSP or special LSI are presented up to now.[7),9)]

In this paper we present a simplifying method to enable a real-time 3-dimensional shape measurement of the human head. Features of our method presented are that an efficient image processor to give raster coordinates of the target images is employed, and also that all the computations to transform the raster coordinates into world coordinate removed due to the employment of a Look-Up Table. In addition to the computation of 3-dimensional coordinate , compensation of locational errors caused by the aberration of the TV camera lens is also incorporated into the Look-Up Table.

Therefore , accurate and real-time measurements become possible even with a low-cost computer without special LSI or DSP. Our method is realized as a 3-dimensional shape measurement system which measures the surrounding shapes of human heads in 4.0 secnds. The system developed consists of a laser-slit ray projector, two CCD TV camera , an image processing unit and a 16-bit computer to control the total system. The slit-ray projector and two CCD TV cameras are mounted on a mechanical arm to rotate and scan the surrounding shape of a human body.
Experimental results reveals its applicability.

2. Measuring System

The setup of the 3-dimensional profile measuring system of a human head developed here is shown in Fig. 1. Overall profile of the system is also shown in Photo. 1. This system is fabricated in order to design custom-made eye-glasses. A laser slit-ray is projected on the human head from the tip of the arm. The slit-ray is generated from a laser beam (2mW) 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 head. The viedo signals of these cameras are alternatively sampled and converted into binary signals by a videl signal processing unit. Since the binary slit-ray images , detected by the TV cameras, are usually broader than desirable, the image prcessing unit detects the raster coordinates of the left and the right edges of the laser slit-ray. Each set of these raster coordinates extracted from slit-ray images are stored on a temporary memory. A 16-bit computer (NEC PC9801RA) reads out these data and obtains the raster coordinates of the centerline of the laser slit-ray by adding and bit-shifting operations. Using the look-up table which include informations about the image distorsion caused by spherical aberration of the TV camera lens and about the geometrical setting of the system , the raster coordinates of the centerline of the slit-ray are translated into the 3-dimensional coordinate.
In order to obtain gloval profile of the human head , the arm is rotated with a step motor at arbitrary fixed rotating speed. Harmonic drive reduction mechanisms is installed in this step motor so that mechanical vibrations and backlash are negligible. After obtaining all the data about the slit-ray images, the 16-bit computer displays the results graphically.

Image Processing Unit

Our system developed employed an image processing unit , which extracts the important information from the video signals and reduces the amount of image data to be processed. Owing to this image processing unit , 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 .

First, this real-time video processing unit digitizes the video signal to one bit with 512*240 pixels per a frame. Since binary slit-ray image sampled is usually broader than desirable, a horizontal thinning operation is given to obtain the

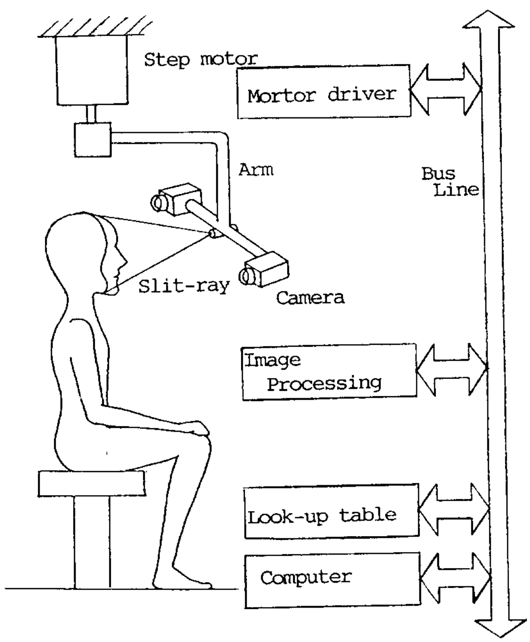

Fig.1 System Configuration

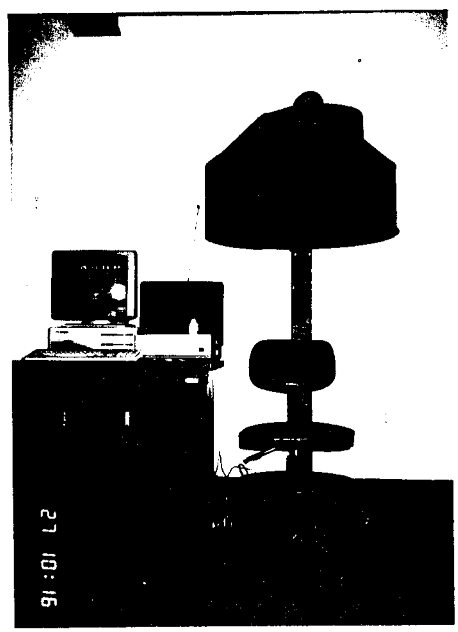

Photo.1 System view

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. When the rise of binary video signal is detected, Edge detector activates Edge signal ⊕ and the horizontal raster coordinate in Counter 1 is preset into FIFO memory. Moreover, when the fall of binary video signal is detected Edge detector activates Edge signal ⊖ and the data in Counter 2 and Counter 3 is stored in the FIFO memory.

Output data of Counter 3 is the vertical raster coordinates. Just after one horizontal scanning on one TV camera has finished, all data stored in the FIFO memory are transfered to a 16-bit computer. The computer converts raster coordinates of target points to 3-dimensional world coordinates using a look-up table.

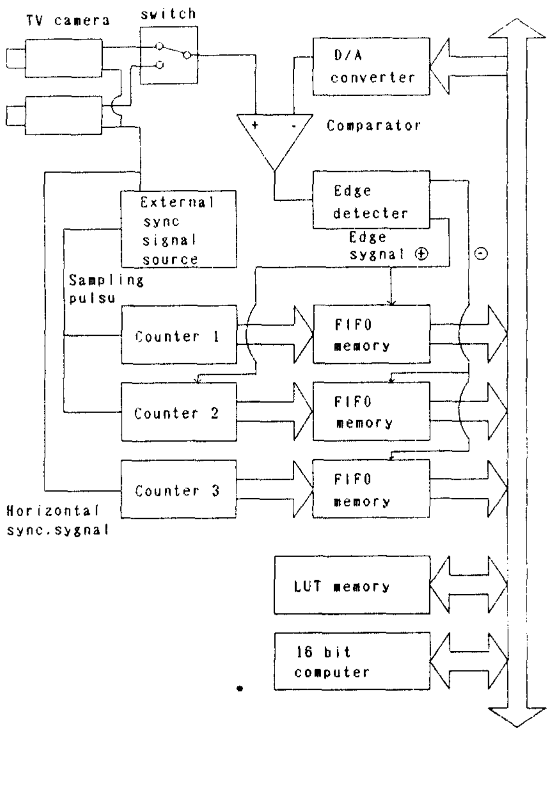

Fig.2 Image processing unit

3. Techniques of Look-up table

Since our system aims to measure forty thousands of target points, some sophisticated technique to process a large number of data in a few seconds is needed. Considering that the data-processing needed can be simplified, a method to use look-up tables is introduced.

While these tables require a relatively large number of memories, the tables allow a simple and fast data-processing.

In the tables employed, all the information about the aberration caused by the TV camera lens and also about the relation between the raster coordinates of the target points and the corresponding world coordinates are embedded.

Correction of lens aberraton

In order to obtain accurate 3-dimensional data, errors caused by the aberration of the TV camera lens need to be corrected.

Experiments to measure base points on the measuring bench are executed to generate the look-up table which transform the raster coordinates (U,V) of the target points to the corrected ones (u,v) (see Fig.3).

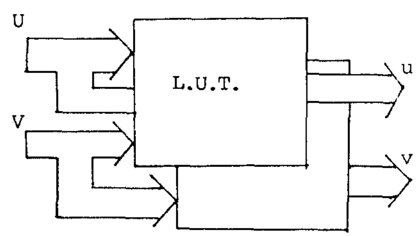

Fig.3 L.U.T for correction

The table is generated only on the base points. Therefore, for the arbitrary raster coordinates (U,V), corrected ones (u,v) are calculated by the linear interpolation using neighbouring four base values.

Calbration

Before calculating the 3-dimensional coordinates of the target points, the geometrical relation between the laser slit-ray projector and two TV cameras have to be calculated. In order to simplify the calculation of the 3-dimensional coordinate, the world coordinate system with the cylindrical coordinates (z, r, θ) is introduced so that z-axis conincides with the axis of the rotating arm. In addition, the laser slit-ray projector needs to be mounted on the rotating arm , so that the laser slit-ray is projected via the z-axis.

The calibration of the laser slit-ray and the TV cameras can be achieved by measruing four base points whose world coordinates are known .

While the arm with the slit-ray projector and the two TV cameras rotates , the slit-ray specifies the target points only on the 2-dimensional surface at every instance .

Therefore , the following equation is obtained basing the principle of the perspective transformation ,

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

where z,r are the cylindrical coordinates of the target points on the slit-ray , u,v are the coorespondig raster coordinatres and h_{ij} represents geometrical arrangement of the 3-dimensional measuring system .

Elimination of λ' in Eq. (1) gives

$$\begin{pmatrix} z & r & 1 & 0 & 0 & 0 & -uz & -ur \\ 0 & 0 & 0 & z & r & 1 & -vz & -vr \end{pmatrix} \begin{pmatrix} h_{11} \\ h_{12} \\ \vdots \\ h_{32} \end{pmatrix} = \begin{pmatrix} u \\ v \end{pmatrix} \quad (2)$$

Augumentation of Eq.(2) for four distinguished base points on the laser slit-ray yields

$$Th=w$$

$$T=\begin{pmatrix} z_1 & r_1 & 1 & 0 & & & -u_1z_1 & -u_1r_1 \\ \vdots & \vdots & & \vdots & & & \vdots & \vdots \\ z_4 & r_4 & 1 & 0 & & & -u_4z_1 & -u_4r_4 \\ & & & 0 & z_1 & r_1 \; 1 & -v_1z_1 & -v_1r_1 \\ & & & \vdots & \vdots & & \vdots & \vdots \\ & & & 0 & z_4 & r_4 \; 1 & -v_4z_4 & -v_4r_4 \end{pmatrix} \quad (3)$$

$$h=\begin{pmatrix} h_{11} \\ h_{12} \\ \vdots \\ h_{32} \end{pmatrix} \qquad w=\begin{pmatrix} u_1 \\ v_1 \\ \vdots \\ v_4 \end{pmatrix}$$

where ui,vi are the raster coordinates for the i-th base point whose cylindinal coordinates are zi, ri, and θ.

Thus , the vector h in Eq.(3) can be obtained

$$h=T^{-1}w \quad (4)$$

Of cource , a more accurate calibration can be expected in case that Eq.(2) is angumented for more than four base points .

In such a case , Eq(4) have to be modified basing a minimum squared error technique as

$$h=(T'T)^{-1}T'w \quad (5)$$

Determination of 3-dimensional coordinates

Once the calibration vector h is obtained by Eq.(4) or Eq.(5),the coordinates z and r of the target point can be determeinded

Elimination of λ in Eq.(1) gives

$$\begin{pmatrix} h_{31}u-h_{11} & h_{32}r-h_{12} \\ h_{31}v-h_{21} & h_{32}r-h_{22} \end{pmatrix} \begin{pmatrix} z \\ r \end{pmatrix} = \begin{pmatrix} u \\ v \end{pmatrix} \quad (6)$$

Inverting the coefficient martrix of Eq.(6) the following equation is obtained

$$\begin{pmatrix} z \\ r \end{pmatrix} = \begin{pmatrix} h_{31}u-h_{11} & h_{32}r-h_{12} \\ h_{31}v-h_{21} & h_{32}r-h_{22} \end{pmatrix}^{-1} \begin{pmatrix} u \\ v \end{pmatrix} \quad (7)$$

Since the calculations of Eq.(7) are necessary for more than ten thousands of target points, one look-up table transforming the raster coordinates u,v to the cylindrial coordinates z,r is introduced (see Fig.4) .

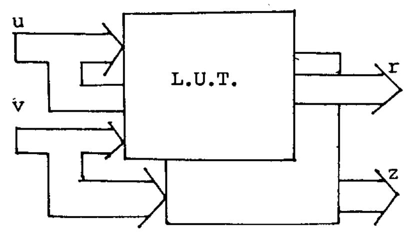

Fig.4 L.U.T. for the determination

It should be noted that two look-up tables in Fig.3 and Fig.4 can be easily incorporated into one look-up table to transform the raster coordinate into the cylindrical coordinate considering the aberration error caused by the TV lens (see Fig.5) .

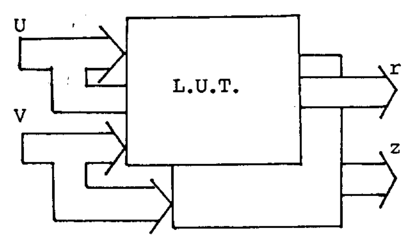

Fig.5 L.U.T. incorporated

The raster coordinates U and V are 9 bits and 8 bits data.
Due to these look-up table , even conventional 16-bit computer is enough to perform fast data-processings .

4. Experimental Results

In order to show the utility of our system ,some experimental results are shown . Photo. 2 shows famous Greek statue 'Agrippa', which is employed as a typical target . Photo. 3 shows the experimental results . The motor speed is adjusted to rotate the arm around the target body in four seconds .

Thus , the results of Photo. 3 are obtained in four seconds and are composed of forty thousand of target data .

Since sampled data are stored as cylindrical coordinates (z, r, θ) , a coordinate transformation from the cylindrical coordinate (z, r, θ) to the raster coordinate (u,v) is necessary in order to regenerate the target body as shown in Photo. 3 by plotting sampled data on the TV display . Such transformation can be executed also via a look-up table .

Photo. 4 shows another experimental result where all the data of the target human head are plotted .

Analysis indicate that the maximum absolute error in position is lens than 1.0 milimeters.

5. Conclusions

A system using a look-up table for rapid 3-dimensional shape measurement has been developed . The 3-dimensional shape is mesaured by projecting a slit-ray and scanning the target body .
Triangulation is used to determine the location of sample points , once the raster coordinates of the target are obtained via an image processing unit . One feature of our system is that all the calcurations to determine 3-dimensional coordinates of the target points are incorporated into a look-up table . Due to this table , even a conventional 16-bit computer is enough to process a large number of image data in a few seconds . Expermental results show that the feasibility of our system .

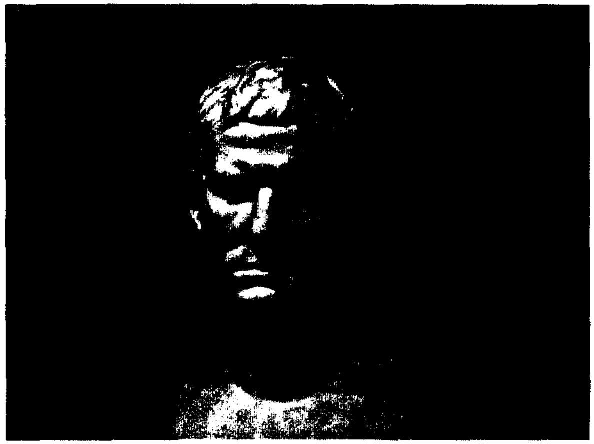

Photo.2 famous Greek statue 'Agrippa'

Photo.3 Experimental Results of 'Agrippa'

Photo. 4 Experimental Results of Human Head

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