3-D Measurement of a Human Body

by

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This paper describes a system which enables a fast 3-dimensional profile measurement of a human body using a slit-ray projection method. One distinctive feature of this system is that a real-time video processor is employed in order to reduce the amount of image data to be processed without eliminating essential information and enable a fast measurement of the human body. Experimental results show that a calibrating method presented for the TV cameras and the slit-ray projector is convenient and enables sufficient accurate measurements.

1. Introduction

3-dimensional information about a human body is very important in many fields, like clothing planning, orthopedics surgery and human engineering. Moire topography is a well-known method since it is a non-contact measurement of a human body with excellent reproducibility.[1] While Moire topography gives 3-dimensional image data using relatively inexpensive apparatus, digital image processing systems are indispensable in order to obtain a large number of numerical data from Moire fringe pattern. Analysis of Moire fringe pattern has some problms. The first one is that the computer employed needs to be highly efficient, since the analysis needs complicated image data processing. Another problem is that the absolute values of 3-dimensional target positions can not be obtained from Moire image pattern.

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. However, the stereometric technique has a disadvantage that the computational complexity to find sets of corresponding points between the two video images and to solve nonlinear equations remains.[4]

A laser slit-ray projection method has a distinctive advantage that the information about 3-dimensional position of the solid object can be computed with simple equations. Therefore, the slit-ray projection method gives numerical data about 3-dimensional target points in a few seconds even with a low performance computer system. Researches on the slit-ray projection method up to now are concerned about the recognition of the object, the improvement of the system in order to eliminate the unmeasurable portions of the object inevitable to this method,[5] stochastic data processing in order to increase the accuracy of the measurement[6] and the improvement of the sampling speed.[7] While slit-ray projection method gives the 3-D information about multiple points on the object, scanning across the solid objects is necessary. Sometimes more than a few minutes are required to scan the scene and to give a low-level image processing. The improvement of the sampling speed is indispensable in order to apply the slit-ray projection method to the measurement of a human body.

This paper describes a system which enables a fast 3-dimensional measurement of a human body

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using a slit-ray projection method.

One distinctive feature of this system developed is that a real-time video processor is employed in order to reduce the amount of image data to be processed and also enable fast measurements of a human body. Also Ozeki, et al. developed a real-time range measurement system using a slit-ray projection method, which adopted a low-resolution CCD TV camera in order to enable real-time calculations of the target points.[7] Comparing their system with ours, a real-time processor employed in our system performs a more skillful processing like a thinning, and more accurate measurement is possible.

Another feature of our system is that two TV cameras are employed in order to eliminate unmeasureable portions of the human body. Only by sampling four target points whose geometric positions are already known, the calibration of the measuring system can be achieved. Due to this calibration employed, 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 body can be obtained, and explaining a real-time processor utilized to extract the useful information. The second part shows how the calibration and the measurement are achieved. Furthermore, experimental results are shown.

2. Measuring System

The setup of the 3-dimensional profile measuring system of a human body developed here is shown in Fig. 1. A laser slit-ray is projected on the human body from the tip of the mechanical arm. The slit-ray is generated from a laser beam (5 mW He-Ne) through a rod lense. Two CCD TV cameras are also mounted on the mechanical arm. These cameras sample the reflected light of the slit-ray projected

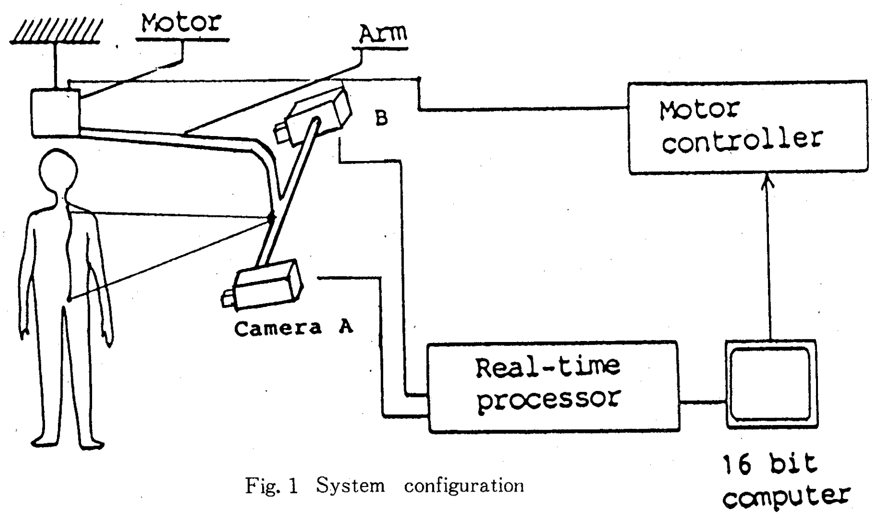

Fig. 1 System configuration

on the human body. The video signals of these cameras are alternatively sampled and converted into the binary signals by a real-time video 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 body, the mechanical arm is rotated by a syncronous motor with 1/8 Hz frequency. After receiving all data about the slit-ray images from the temporary memory, a 16-bit computer (NEC PC-9801VX) calculates the 3-dimensional coordinates of the human body and displays the results graphically.

3. Real-tem video processor

Our system developed employed a real-time video 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 sync 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 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 of the slit-ray image. Therefore, it is preferable to settle the TV cameras on the mechanical arm 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

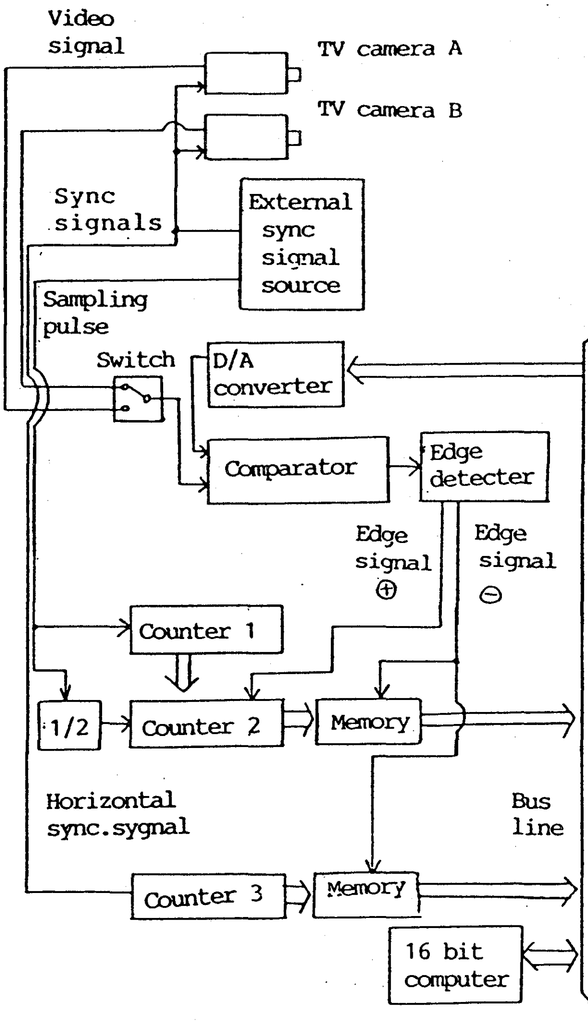

Fig. 2 Block diagram of real time video processor

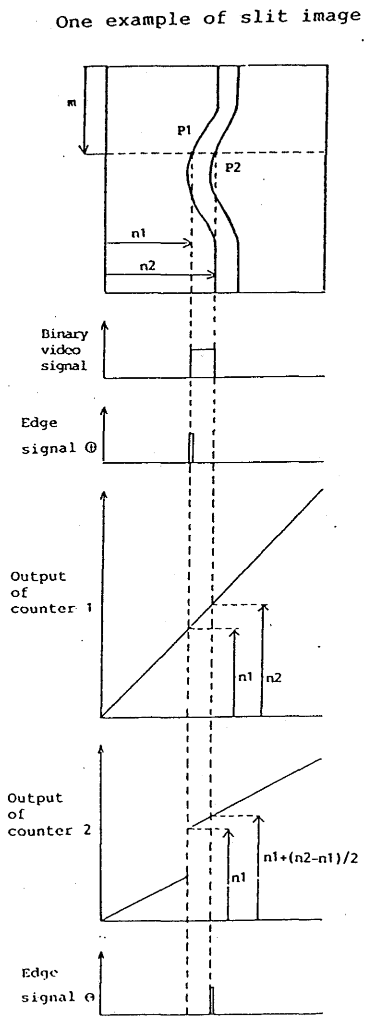

Fig. 3 Timing chart

are shown. When the rise of binary video signal is detected (at P_1 in Fig. 2), Edge detector activates Edge signal ⊕ and the raster coordinate n_1 is preset into Counter-1. Moreover, when the fall of binary video signal is detected (at P_2 in Fig. 2) Edge detector activates Edge signal ⊖ and the data in Counter-2 and Counter-3 are stored in the memory. Since incrementing speed of Counter-2 is reduced to half by the frequency divider, output data of Counter-2 becomes $(n_1+n_2)/2$ which corresponds to the horizontal raster coordinate of the midpoint of P_1 and P_2. Output data of Counter-3 is the vertical raster coordinate m. Just after one vertical scanning on the TV camera has finished, all data stored in the memory are transfered to a 16-bit computer.

4. Calibration

Before measuring the 3-dimensional profile of the target body, calibrations of the TV cameras and the laser slit-ray projector are necessary. Furthermore, the calibration of the rotating axis of the arm is also necessary. In our system the calibrations can be achieved by sampling four 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 are 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 corresponding raster coordinates be u, v. Then the following equation is satisfied,

$$\lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} & h_{14} \\ h_{21} & h_{22} & h_{23} & h_{24} \\ h_{31} & h_{32} & h_{33} & h_{34} \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \qquad (1)$$

where the elements h_{ij} represent the relationship between the two coordinates.

It is well-known that based on the minimum squared error technique these h_{ij} 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.

Suppose the slit-ray plane expressed by the following equation.

$$a_1x+a_2y+a_3z+a_4=0 \qquad (2)$$

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

$$\lambda \begin{bmatrix} u \\ v \\ 1 \\ 0 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} & h_{14} \\ h_{21} & h_{22} & h_{23} & h_{24} \\ h_{31} & h_{32} & h_{33} & 1 \\ a_1 & a_2 & a_3 & a_4 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \qquad (3)$$

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

$$\xi \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \\ m_{41} & m_{42} & 1 \end{bmatrix} \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \qquad (4)$$

where coefficents m_{ij} represent the configurations of the TV cameras and the laser slit-ray.

Using the above equation which represents the relation between the world coordinates x, y, z and the raster coordinates u, v instead of Eq. (1), coefficients m_{ij} can be determined by the following procedure. Let the world coordinates of the distinguished four points which are on the slit-ray plane be x_i, y_i, z_i $(i=1\sim4)$ and corresponding raster coordinates u_i, v_i. Rearranging Eq. (4) yields

$$Tm=w \qquad (5)$$

where

$$T=\begin{bmatrix} u_1 & v_1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & -u_1x_1 & -v_1x_1 \\ 0 & 0 & 0 & u_1 & v_1 & 1 & 0 & 0 & 0 & -u_1y_1 & -v_1y_1 \\ 0 & 0 & 0 & 0 & 0 & 0 & u_1 & v_1 & 1 & -u_1z_1 & -v_1z_1 \\ u_2 & v_2 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & -u_2x_2 & -v_2x_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & 0 & u_4 & v_4 & 1 & -u_4z_4 & -v_4z_4 \end{bmatrix}$$

$$m=\begin{bmatrix} m_{11} \\ m_{12} \\ m_{13} \\ m_{21} \\ \vdots \\ m_{42} \end{bmatrix}, \quad w=\begin{bmatrix} x_1 \\ y_1 \\ z_1 \\ x_2 \\ \vdots \\ z_4 \end{bmatrix}$$

Since the coefficient matrix T and the vector w 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

$$m=(T'T)^{-1}T'w \qquad (6)$$

where the matrix $(T'T)^{-1}T'$ 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).

It is important to note that the above calibration of the TV cameras and the slit-ray have to be executed under the condition that the rotating arm is fixed to the specified angle. Since the TV cameras and the slit-ray 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 can be achieved by sampling a circular cylinder whose geometric measures are known in advance. By sampling the circular cylinder from the rotating arm, the world coordinates of the rotating arm can be calculated. The solution is self-evident and is omitted here.

5. Experimental Results

In order to test the utility of our system developed, one experimental measurement is performed. Fig. 4 shows one experimental result, where 240 image data are processed and 3-dimensional coordinates of totally 48000 points around the human body are measured in 8.0 second. In Fig. 4(a) the data are plotted so that the human body is regenerated. In this figure, a quater of the data are omitted so that the regenerated gloval profile becomes more understandable. In Fig. 4(b) horizontal cross sectional views obtained by the data are shown.

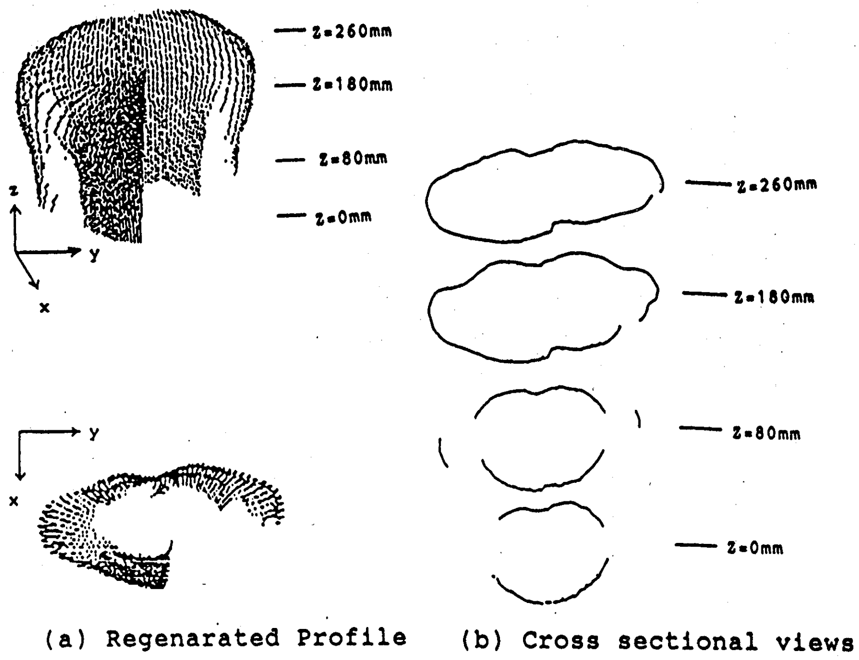

Fig. 4 Experimental results

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

Analysis indicates that the average absolute error in position measured by our system here is not greater than 4.0 milimeters.

6. Conclusions

A system which enables a fast 3-dimensional profile mesurement of a human body using a slit-ray projection method is developed. Due to an employment of a real-time video processor, the measurement of the gloval profile of the human body finishes in 8.0 seconds and more than 48000 points of data are obtained. The real-time video processor extracts the necessary information from the video signal and reduces the amount of image data to be processed. Experimental results show that the method of calibrating the TV cameras and the slit-ray projector used in our system is convenient and sufficiently accurate.

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