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<Technical Paper>

Development of a Low-Cost Industrial Eye that Recognizes the Position and Size of Holes†

Won-Jee Chung* and Chong-Won Lee**

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가공 원공의 위치 및 내경을 인식하는 저렴한 Industrial Eye의 개발

정 원 지 · 이 종 원

초 록

가공 원공의 위치 및 내경을 인식할 수 있는 간단한 컴퓨터 시각 시스템을 개발하였다. 아날로그 영상 자료로 부터 디지탈 자료를 얻기 위한 시스템은 폐쇄회로 TV 카메라와 제어 회로 및 A/D 변환기와 schmitt trigger를 부대한 마이크로 컴퓨터로 이루어 졌으며 원공을 인식하는 알고리듬은 기울기(gradient) 기법을 이용한 경계법(thresholding)과 최소자승법에 의한 curve fitting으로 구성되어 있다.

개발된 시스템은 real time 방식이 아님에도 불구하고 검사 원공의 위치 및 내경을 영상해상도의 오차 범위 내에서 인식할 수 있음을 실험을 통하여 보였다.

1. Introduction

Nowadays the computer vision is providing a powerful sensory tool for robot control[1] and for important applications to automated inspection.[2] Although many commercial image digitizers are already available, they are usually too expensive to be used for relatively simple operations. The current work aims at developing a simple, low-cost industrial eye to recognize the position and size of holes. It includes development of a video interface system incorperated with an already existing microcomputer in the laboratory and the software required for subsequent image processing.

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*Graduate Student

**Member, Mechanical Engineering Department, KAIST

2. Development of a Video Input System for MINC-11 Microcomputer

In order to process the input image and to extract necessary information by a digital computer, the analog input image should be digitized. In this section, we briefly describe a relatively simple and low-cost video image digitizer developed especially for MINC-11 microcomputer.

2.1. Scanning Mechanism[3]

A frame is divided into two parts by interlacing the horizontal scanning lines in two groups. One has the odd-numbered lines and the other the even-numbered lines. A group of odd or even lines is called a field. Interlaced scanning mechanism is generally used because the flicker is negligible with 60 views of the picture presented each second.

Analog video signal consists of picture informaiton signal and two synchronizing pulses, horizontal and vertical. The horizontal synchronizing pulse(H. sync) retraces the video beam at the end of each horizontal line quickly to the beginning point to start the next line, and the vertical synchronizing pulse (V. sync) retraces the beam at the bottom of the picture tube to the top of it. The specifications of scanning mechanism are given in Table 1.

Table 1 Specifications of scanning mechanism

Camera type	OPC model No. OTC 1810 vidicon CCTV camera
Vertical scanning rate (frame frequency)	30Hz
Number of horizontal scanning lines per frame	525
Number of horizontal scanning lines per field	$262\frac{1}{2}$
Horizontal scanning rate (time)	15,750Hz (63.5μsec)

2.2. The Structure of the Video Digitizer System

The video digitizer system developed does not operate in real time mode because of the limited speed of the A/D converter in MINC-11 microcomputer[4].

The specifications of this system are;

(1) The standard NTSC (National Television System Committee) television system is employed,

(2) The ADV 11-A board is used as an A/D converter,

(3) The KWV 11-A board is used for interrupting the C.P.U. of MINC-11 and initializing A/D conversion,

(4) Capture time is 4.26(1/30×128) sec for 128×128 image size, and

(5) Brightness Resolution is 12 bits/pixel.

Fig. 1 illustrates the block diagram of the whole video interface system. A vidicon CCTV (Closed Circuit Television) camera is selected as a standard

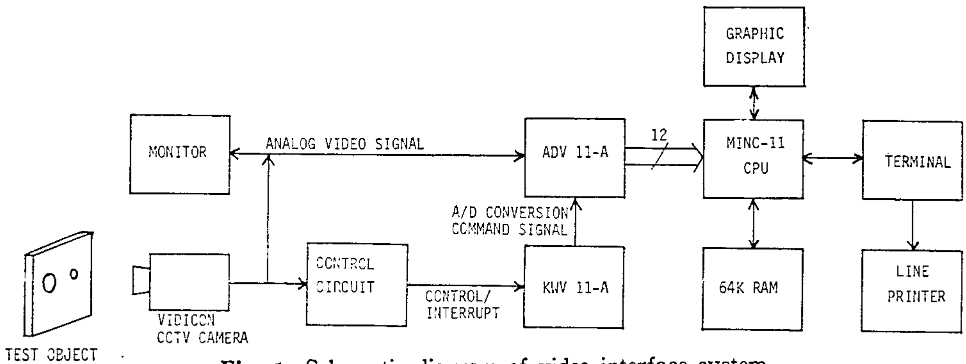

Fig. 1 Schematic diagram of video interface system

sensing device for static images, due to its availability and cheapness.

The camera is located perpendicular to the object plane so that the image can be considered as 2-dimensional object. The control circuit produces appropriate control/interrupt signal from analog video signal in consideration of capability of ADV 11-A. The control/interrupt signal enters a Schmitt Trigger(ST) of KWV 11-A. Owing to the limitation in conversion speed, only one pixel (picture element or picture cell) is supposed to be digitized as each line is scanned, and the digitized 12-bit words are stored in 64K RAM[5,6].

In Fig. 2, the block diagram of the control circuit for 128×128 image size is shown. The input to this circuit is the analog video signal from the vidicon CCTV camera, and the output is the control/interrupt signal. The H. and V. syncs are extracted from the analog video signal through the sync separator. The H. sync enables the clock generator (4.25 MHz) and the clock signal is counted at COUNT 2. The COMP. 1 checks wheter the number counted at COUNT 1 is equal to the preset vertical width data (i.e., 128) or not. On the other hand,

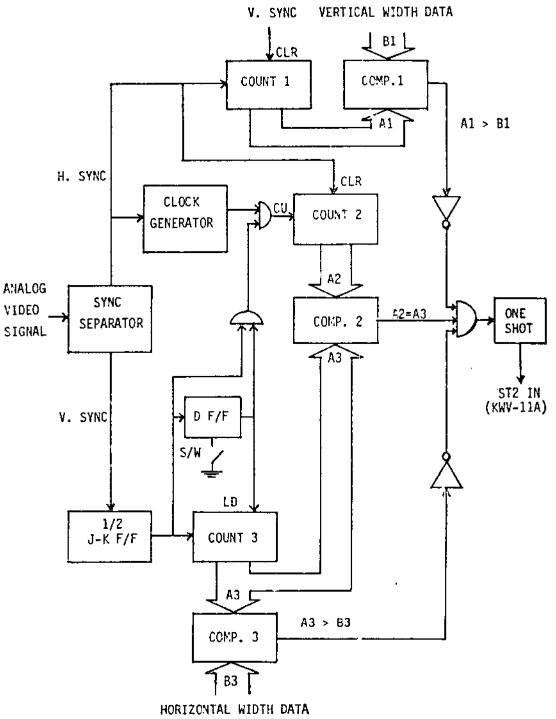

Fig. 2 Block diagram of control circuit

the V. sync enters J-K F/F and is toggled by half period. The toggled V. sync enters the clock pulse input pin of D F/F and the count-up input pin of COUNT 3. The D F/F, which is operated by a manual S/W, is used for synchronizing the starting point in this whole system. The D F/F holds high state after V. sync appears and loads COUNT 3 to 1 at the starting point, i.e., the D F/F puts the initial value to 1. The contents of COUNT 2 is incremented by 1 at every other line, but COUNT 3 remains unchanged unless a complete frame is scanned. COMP. 2 compares the number counted at COUNT 2 with that counted at COUNT 3. When both numbers are equal, then COMP. 2 produces the high state. If both contents of COUNT 1 and COUNT 3 are less than the preset image size, i.e., 128, the output of COMP. 2 is transferred to the next stage. In the monostable multivibrator(74 LS 123), the control signal produced in previous stages is adjusted to interrupt the MINC-11 C.P.U. or to initiate A/D conversion. Detailed control circuit is given in [6].

3. Development of Basic Algorithms

The grey level data of an image can be formed as binary data by thresholding using gradient. Then least squares circular curve fitting is employed in order to find the center of a hole and its radius.

Algorithm 1 : Thresholding Using Gradient[7]

Input: Picture matrix $f(i, j)$

Output: Binary martrix $s(i, j)$

Steps:

(1) For each (i, j) compute the gradient norm by taking the average $g(i, j)$ of the absolute values of the difference between $f(i, j)$ and $f(i+1, j)$, $f(i-1, j)$, $f(i, j+1)$, $f(i, j-1)$ respectively. If $g(i, j)$ exeeds a threshold H, set $h(i, j)=1$, else $h(i, j)=0$.

(2) Form the histogram of $h(i, j)\times f(i, j)$ and choose a threshold T at a valley of the histogrm.

(3) Perform a threshold operation on $f(i, j)$ with T to obtain $s(i, j)$.

$$s(i, j)=\begin{cases}1 \text{ if } f(i, j)\geq T\\ 0 \text{ if } f(i, j)<T\end{cases}$$

The auxiliary matrix $P(i, j)$ contains the points of significant change in brightness. It is usually easier to choose H rather than T. This search may be made only once for a class of typical pictures.

Algorithm 2 : Least Squares Circular Curve Fitting

The general equation of circle is

$x^2+y^2+ax+by+c=0.$

Let the above equation be equal to an error function, then square the error and sum it over the n existing frequencies

$$\sum_{i=1}^{n} E^2=\sum_{i=1}^{n}(x_i^2+y_i^2+ax_i+by_i+c)^2.$$

Now differentiate with respect to a, b and c, and the result to zero.

$$\frac{\partial \Sigma E^2}{\partial a}=2\Sigma(x^2+y^2+ax+by+c)x=0$$

$$\frac{\partial \Sigma E^2}{\partial b}=2\Sigma(x^2+y^2+ax+by+c)y=0$$

$$\frac{\partial \Sigma E^2}{\partial c}=2\Sigma(x^2+y^2+ax+by+c)=0$$

In the matrix form the above equations become

$$\begin{bmatrix} \Sigma x & \Sigma y & n \\ \Sigma xy & \Sigma y^2 & \Sigma y \\ \Sigma x^2 & \Sigma xy & \Sigma x \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} -\Sigma(x^2+y^2) \\ -\Sigma(x^2y+y^3) \\ -\Sigma(x^3+xy^2) \end{bmatrix}$$

Solving the matrix equation for a, b and c, we obtain

$$x_{\text{Center}} = -\frac{1}{2}a$$

$$y_{\text{Center}} = -\frac{1}{2}b$$

$$\text{Radius} = \sqrt{\frac{a^2}{4}+\frac{b^2}{4}-c}$$

4. Experiments and Results

The overall apparatus is shown in Fig. 3 where the test object, a vidicon CCTV camera, a monitor, a control board, and a power supply are shown. The procedure to obtain the position and size of holes from image data is summarized in Fig. 4. Figs. 5. and 6 show the processed images before and after the least squares circular curve fitting, respectively. Those images are displayed on Tektronix 4010 graphic terminal. Calibration of the image dimensions is made by using the measured actual distance between two holes as a reference. The recognized diameters of two test holes are shown in Table 2. It indicates that this industrial eye successfully detetcs the diameters of holes within the error bound of less than 1 mm which is of the same order as the image resolution.

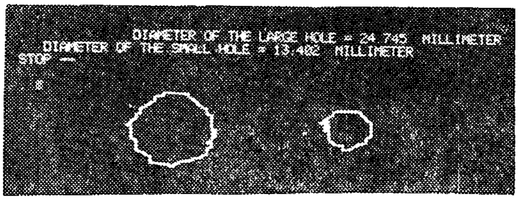

Fig. 5 Processed image before curve fitting

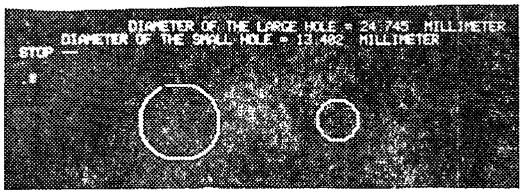

Fig. 6 Processed image after curve fitting

Table 2 Experimental results

	Large hole	Small hole
dia. measured by a vernier caliper(mm)	25.250	12.650
dia. detected by the industrial eye(mm)	24.745	13.402
absolute error(mm)	0.505	0.752

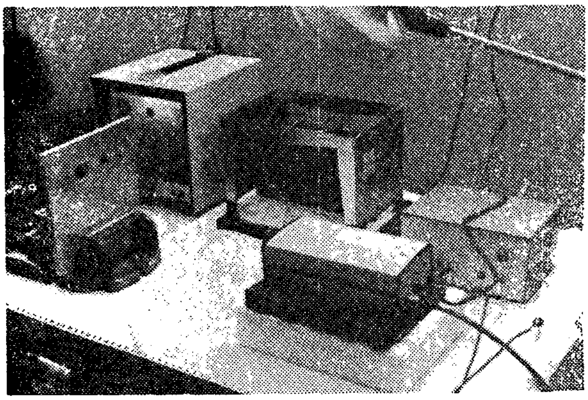

Fig. 3 Experimental set-up

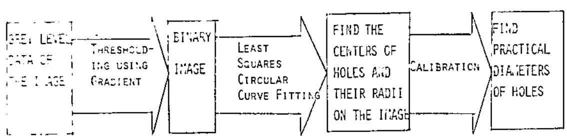

Fig. 4 Procedure of image data processing

5. Discussions

A simple and low-cost, say about one million wons, industrial eye has been developed to detect the size and position of holes in the laboratory. This system can be further developed for use in industrial inspection by sensor-based robots. The digitizer does not operate in real time mode. It is, though, tolerable since the time needed for digitization is much shorter than image processing.

Through the experiments it has been experienced that good illumination should be provided in order to ensure the good quality of the images. Especially the intensity and the direction of light sources should be carefully adjusted.

Further development of the industrial eye, including automatic zooming and focusing, is in progress.

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