AUTOMATIC DETECTING SYSTEM OF ROLL SHAPE USING CCD SENSOR IN PLATE ROLLING①

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ABSTRACT A new real-time roll camber detecting system was described. A highly sensitive CCD camera was used to produce images. The image processing hardware and software provided image aquisition, treatment, distribution and other functions. Both theoretical and experimental results have proven the capability of the CCD detector in presenting the high speed and accurate detection.

Key words roll camber digital image processing CCD sensor regression analysis

1 INTRODUCTION

During plate rolling, the correct shaping of the rolls is one of the important operating factors which governs the obtaining of a good quality material [1], and the increasing of plate productivity. In hot rolling, the roll force, fractional damage and temperature of the rolls are especially important, which have influence on the roll shape. Clearly, the factors above must be considered to keep the correct shape and these factors are unavoidable. Metal expands with heat and retracts when cooled. So in order to acquire the correct roll shape, a chilled liquid flow is regulated separately, which is used to control the real dimension of each section of the hot roll. A certain steel corporation in China has used this method and acquired good plate shape as well as high final plate productivity under the condition of significant improved roll shape.

But the operators detected the shape of the roll gap by visual inspection, so it was not very reliable. For the purpose of controlling the cold liquid flow, the best way is to develop a real time detecting system to measure the variation of the roll gap. So we designed an automatic detecting device of roll shape, which used a linear array solid CCD camera to measure the distance between two rolls from point to point in certain order, then analyzed the precise roll shape of each roll according to mathematics models.

2 SYSTEM DESCRIPTION

The system we have developed is shown schematically in Fig. 1.

To increase the sensitivity of CCD camera and overcome the interference coming from the adverse circumstances, the detecting system uses the monochromic laser as the lamp house. The CCD camera and the lamp are located on the same side of the roll frame for the reason that there are other mechanical devices located there. The arrangement is shown schematically in Fig. 1(a). A reflecting mirror is placed on the other side opposite the CCD camera. Lights go through the roll gap, reflect from the mirror and are received by the CCD sensor.

The CCD sensor used in our system is TCD 141c 5000-element linear array CCD. Dimension of every element is 7 μm × 7 μm. The CCD video signals digitized with a high speed analog-to-digital converter, and then transferred to a microcomputer for storage and processing.

The procedure of measurement is as follows: choosing several positions along the axial directions of rollers, the camera, which is drive along with laser by a step motor , measures the

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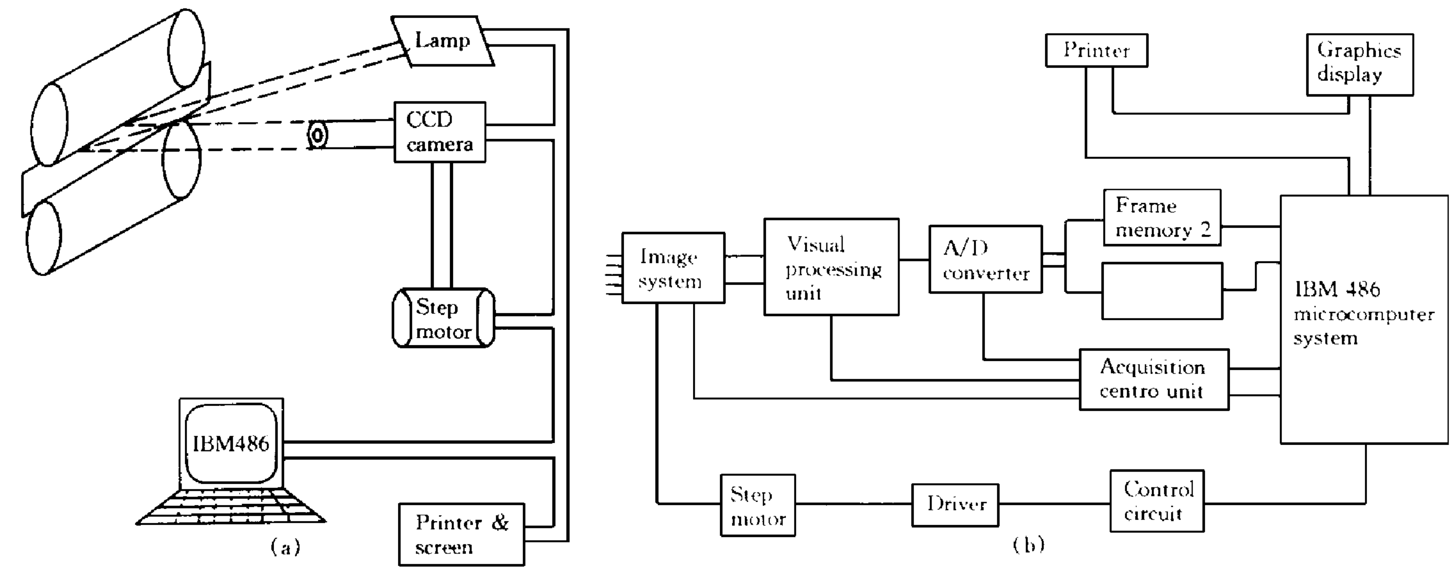

Fig. 1 The schematic diagram of our system(a) and its functional block diagram form(b)

distance between two rolls in every point in sequence. After processing these data, the computer presents the integral curve of the roll gap.

3 COMPUTER IMAGE PROCESSING

When the roll gap in one position is measured, the video signal of the roll gap will be displayed on the screen. However, to arrive at the precision prescribed, there still exist some problems. We know that the changes or discontinuities in an image attribute such as luminance, tristimulus value or texture, are fundamentally important primitive features of an image since they often provide an indication of the physical extent of objects within the image. It means that the exact edge between the object and the background must be determined.

A common approach to monochrome edge detection is illustrated in Fig. 2, in which an original monochrome image $F(j, k)$ undergoes a gray scale edge enhancement by linear or nonlinear processing to produce an image field $G(j, k)$ with accentuated spatial brightness changes. Next, a threshold operation is performed to determine the pixel location of significant edges[2].

Threshold selection is one of the key issues in edge detection. We adopt a robust and completely deterministic fast thresholding method, using a gradient intensity average value as threshold value[3].

An image may be subject to noise and interference from several sources including electrical sensor noise, and channel errors. Noise in an image generally has a higher spatial frequency spectrum than the normal image components because of its spatial decorrelation. Hence simple low-pass spatial filtering can be effective for noise smoothing. For one-dimensional roll gap video signal, Kalman filter is a useful noise clean

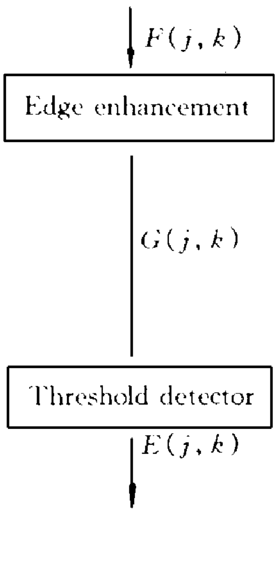

Fig. 2 Edge detection

ing method[4]. Before edge enhancement noise should be cleaned[5].

3.1 Optimal real-time filter

The most effective noise-reduction method for a step edge is the Kalman filter, which can acquire the optimal filtering result. Its basic algorithm can be expressed as

$$Y(N) = AY(N-1) + BX(N)$$

where A and B are constants. If $A + B < 1$, the stability and performance of the filter are insured. Kalman filter algorithm provides a simple and convenient method for noise reduction. For example, if we set $A = 0.99$, $B = 0.0091$, which is valued carefully, the result is very well. Fig. 3(a) shows the raw video signal between two analogue rolls at a point. Fig. 3(b) indicates the Kalman filtering image of Fig. 3(a).

3.2 Image sharpening

Our task is to determine the exact image boundary which is related to the measurement accuracy of the distance between two rolls. So, it is necessary to use the one-dimensional first-order, that is, edge shaping to return to the step-edge image which contains little noise after Kalman filtering. The first-order deviation can be written as follows:

$$\Delta_j f(i, j) = f(i, j) - f(i, j-1)$$

where $f(i, j)$ denotes the gray value of the point (i, j) and $f(i, j-1)$, of the point before $f(i, j)$.

3.3 A rapid and strong robust thresholding method

In arriving at the precision prescribed, the further way is to determine the exact boundary between the roll and the background, in which choosing the threshold is the key step. This paper presents a robust and completely deterministic method for gray-level picture thresholding, which uses gradient mean intensity as threshold. The method provides the edge detecting process with the reliability and rapidity. The relevant equations are listed as follows:

Let $N \times 1$ be a CCD image data size. At point j:

$$H_1(i) = \sum_{j=0}^{n}(g(j) \mid f(j) = i) \qquad (1)$$

where "|" represents the condition;

$g(j)$ —the directional gradient at the corresponding point;

$f(j)$ —the gray scale of the corresponding pixel;

$H_1(j)$ —the gradient sum of all pixels, each pixel with gray scale i.

The mean gradient intensity is:

$$T = \left(\sum_{i=0}^{n} i \times H_1(i)\right) / \left(\sum_{i=0}^{n} H_1(i)\right) \qquad (2)$$

where N —gray level number.

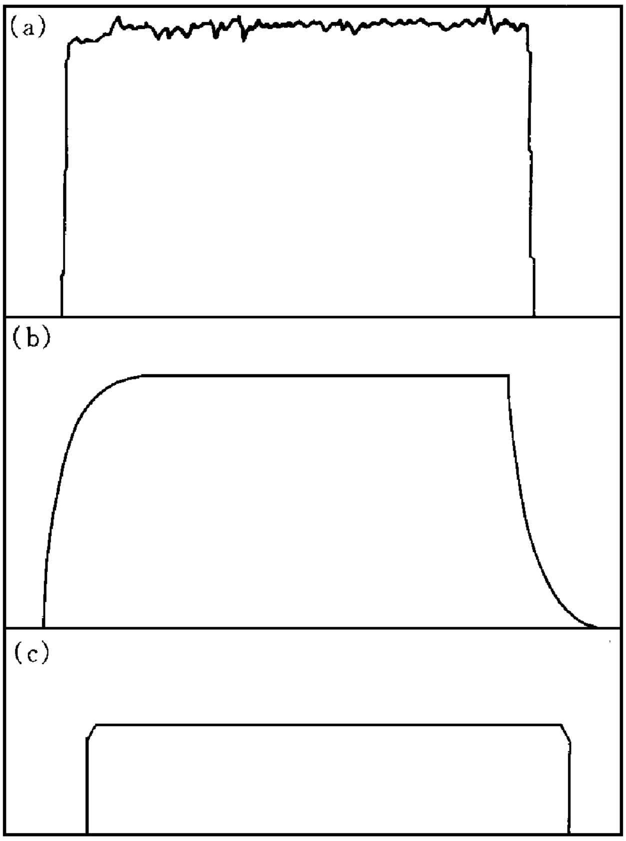

Fig. 3 Image process result
(a) —raw video signal;
(b) —Kalman filtering image;
(c) —image after determining the threshold

Using mean gradient intensity as threshold is reasonable. We choose two-threshold method to further limit the range in which the exact boundary lies. Fig. 3(c) shows the image after thresholding.

3.4 Linear center of mass method

We use linear center of mass method to determine the exact boundary.

Let $f(i)$ be the gray value of every CCD element between points M and N relative to the two thresholds, then the center of mass P, the real edge, is expressed as

$$P = \frac{\sum_{i=M}^{N}[i \times f(i)]}{\sum_{i=M}^{N} f(i)}$$

4 THE ANALYSIS AND PROCESSING OF THE MEASUREMENT DATA

Graphical plot and regression equation are available to data processing[6] and mathematics models[7]. Interpolation is a useful method for getting the roll gap curve in graphical plot[8], and acquiring the line of roll edge.

Two steps should be followed in regression analysis:

(1) deciding what form of relationship should be fitted and determining the equation of that form which can fit the available data better.

(2) deciding how well the data are represented by the fitted equation and putting confidence limits on predicted values.

5 RESULTS

The experimental work is conducted to quantitatively illustrate the performance of the CCD detecting system.

Table 1 shows a group of measured data. This is compared with the practical data of the model which has been calibrated by testing center. The measured data is remarkably close to the practical data.

The regression curve which is almost the same as the model curve has been proven very successful.

Table 1 Experimental data (mm)

Position	10	20	30
Practical data	11.8125	12.1440	12.3944
Measured data	11.8125	12.1431	12.3900
Position	40	50	60
Practical data	12.5638	12.6522	12.6596
Measured data	12.5643	12.6560	12.6651
Position	70	80	90
Practical data	12.5861	12.4316	12.1961
Measured data	12.5790	12.4397	12.1961

6 CONCLUSION

The data displayed here represent only the experiments data obtained in our laboratory. More improvements will be achieved by improved hardware and software designs.

The performance of the CCD detector and the experimental results predict that such a detector promises to find wide application in precision measurement.

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