Application of linear scan camera sytem to motion analysis

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ABSTRACT

With limited spatial and temporal resolution of video recording camera, it is very difficult task to analyze object motion with higher accuracy. In addition, target object or target points of object in one-frame can be hardly recognized automatically in ordinary two-dimensional video recordings. If correlation or template matching methods is used to detect object position, initial object area or template should be decided manually. So fully automatic detection process is difficult.

But with linear scan camera (LSC) utilizing line-image sensor, object position detection can be done easily with much higher accuracy. This article describes this feature of LSC in motion analysis. First d-value is introduced to evaluate correlation of two line images. This d-value is calculated in quarter pixel width for higher accuracy. Object displacement between given two-line image can be decided by monitoring this d-value. Steep drop of d-value means match of lines and higher correlation. Because d-value increases as line separation becomes bigger, this variation should be checked simultaneously for consistency. Typically over about 100-line separation this value increases, so pivoting line (template line) should be changed.

Selecting suitable combination of two lines based on d-value will be important for overall accuracy of time-displacement analysis Two lines should be selected to decide pixel shift where spatial quantum error is minimum. Suitable two line images can be selected by searching less d-value. Prior to that, two-dimensional d-value table should be made. Then one-pass trace of suitable two-line selection is carried out for time-velocity analysis.

Fully automatic analysis method of position detection with LSC was proposed. To estimate object displacement, d-value was introduced and its validity was proved experimentally. In addition, by selecting suitably separated two points, resultant velocity at middle point can be much accurate than direct differentiation of time-displacement data.

Keywords: Linear image sensor, Template Matching, Network distribution

1. INTRODUCTION

With limited spatial and temporal resolution of video recording camera, it is very difficult task to analyze object motion with higher accuracy. In addition, in ordinary two dimensional video recordings, target object or target points of object in one-frame can be hardly recognized automatically. If some type of correlation or template matching method is used to detect object position, initial object area or template should be decided manually. So fully automatic detection process is difficult.

But with linear scan camera (LSC) utilizing line-image sensor, object position detection can be done easily with much higher accuracy. This article describes this feature of LSC in motion analysis. Whole line image data is used as template for correlation to another whole line image data. d-value was introduced for evaluation of correlation. Suitable two line images can be selected by searching less d-value. Prior to that, two-dimensional d-

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value table should be made. Then one-pass trace of suitable two-line selection is carried out for time-velocity analysis.

2. BASIC CONCEPT OF LINEAR SCAN CAMERA

Fig. 1 shows basic concept of this proposed linear scan camera. This camera compiles line-images sampled at given time interval into two-dimensional image. Thus resultant image or trajectory of object in motion can be observed and analyzed. So this image is much similar to those obtained by traditional streak cameras. Typical sample image is shown in Fig. 2. The horizontal axis is space and the vertical axis is time. Because object steel ball (diameter: 25.5mm) drops freely, resultant trajectory displayed in Fig. 2 is parabolic curve. Spatial resolution of one line image is 4096, which is decided by linear image sensor in camera head. Maximum read-out clock of this sensor is 60 MHz. Minimum time interval between lines is 210 μsec.

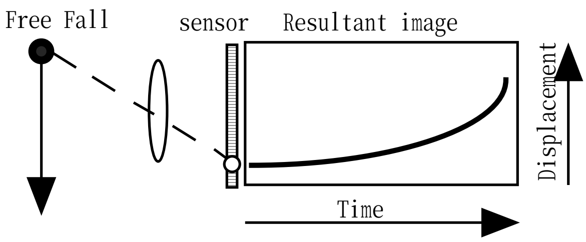

Figure 1. Basic concept of linear scan camera

Figure 2. Typical resultant image by LSC

3. POSITION DETECTION BY CROSS-CORRELATION

Resultant image can be analyzed line by line basis. To make this process fully automatic, the following evaluation d-value is calculated in given shift value. Here pixel shift varies in quarter pixel width. Linear interpolation method is used to decide between-the-pixel intensity. Estimated shift value of line image is evaluated by R.M.S. of two line image intensity arrays. Intensity will be used by cyclic, so positive and negative shift value can be detected. And whole line data is used, i.e. 4096 data points.

$$D(n,m,s) = \sqrt{\frac{\sum_{p=0}^{4095} (i_{n,p} - i_{m,p+s})^2}{4096 \times 4.0}} \tag{1}$$

where $i_{n,p}$ denotes image intensity at p-th position of n-th line data. Here pixel pitch is shifted by quarter-pixel width, so p varies from 0 to 4095*4.0 actually.

Fig. 3 shows variation of this d-value in typical situation. In this case, 50th line data is compare to 100th line data. The steep drop of d-value can be recognized in around 400-pixel position. This drop gives shift value in quarter pixel width. And this value also gives object displacement between 50th line and 100th line, where time of sampling of these lines can be decided separately. So highly accurate time-position data of moving object can be analyzed using relatively simple method. This is simple but time-consuming one, because whole line must be compared with another whole line data with quarter pixel width shift value. But typical calculation time of this d-value is 1.0 second for one-line pair comparison. This is done by Intel Pentium II (400MHz) machine.

Fig. 4 shows analyzed displacement variation from Fig. 2, pivoting 50th line data with respect to from 50th to 300th line data. So displacement variation from 50th line to 300th line is acquired. Because d-value increases as line separation becomes bigger, this d-value variation should be checked simultaneously for consistency.

Fig. 5 shows this d-value variation with respect to line separation 0 to 250 lines. Over about 100-line separation this value increases, so pivoting line (template line) should be changed. Selecting suitable combination of two lines based upon d-value will be important for accuracy. Two lines should be selected to decide pixel shift where spatial quantum error is minimum.

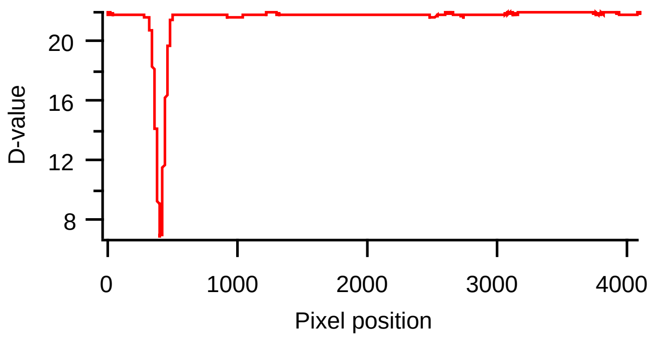

Figure 3. d-value variation with shift

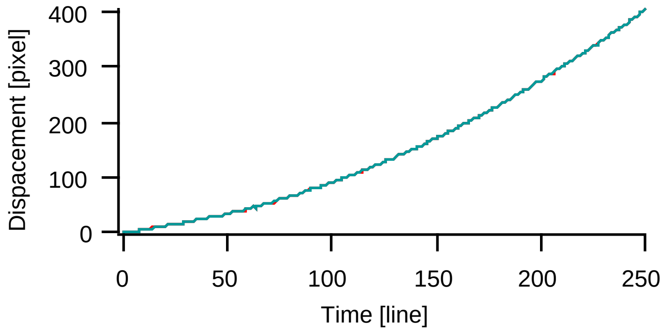

Figure 4. Analyzed displacement with time

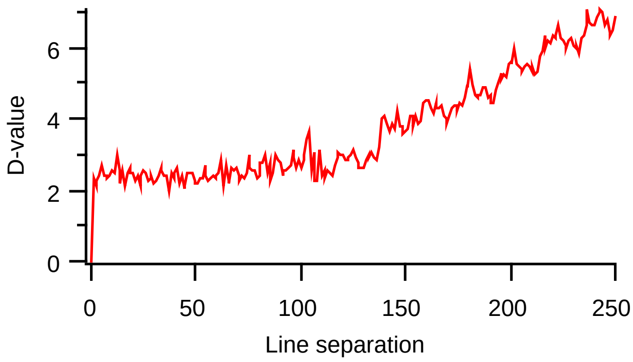

Figure 5. d-value variation with line separation

Selecting suitable combination of two lines based upon d-value is required for quantum error reduction. First all combination of d-value table as to two line selection should be made. Then successive suitable two-line selection should be done for velocity calculation. Table 1 shows this two-dimensional d-value table.

Table 1. Two dimensional table of d-values

	0	1	2	.	1023
0		D_{0-1}	D_{0-2}		D_{0-1023}
1	$D_{1-0} = D_{0-1}$		D_{1-2}		D_{1-1023}
2	$D_{2-0} = D_{0-2}$	$D_{2-1} = D_{1-2}$			D_{2-1023}
.					
1023	$D_{1023-0} = D_{0-1023}$	$D_{1023-1} = D_{1-1023}$	$D_{1023-2} = D_{2-1023}$		

And Fig. 6 shows flow chart of successive two-line selection suitable for velocity calculation. Typical start position is the first line. Average velocity, which equals instant velocity at the middle point of two sampled data points can be calculated by suitably separated two measurement points. Fig. 7 shows this principle. Object motion in this case is free fall of steel ball, so average velocity of spatially separated two points equals instant velocity at the middle point. Then picking up points separated in rather big span and calculating velocity based on these points, quantum error reduction can be done. Fig. 8 shows velocity variation as to time that is calculated from direct differentiation from displacement vs. time data. Due to large fluctuation of velocity, acceleration can not be acquired from this results. Contrary to that, Fig. 9 shows velocity variation as to time, which is calculated by suitably separated two-point method. In this case fluctuation of velocity is much smaller.

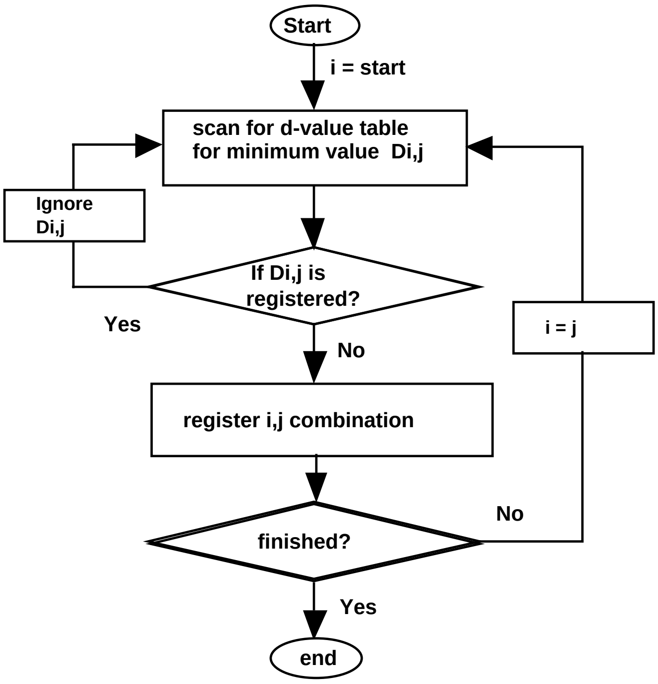

Figure 6. Flow of suitable two-line selection

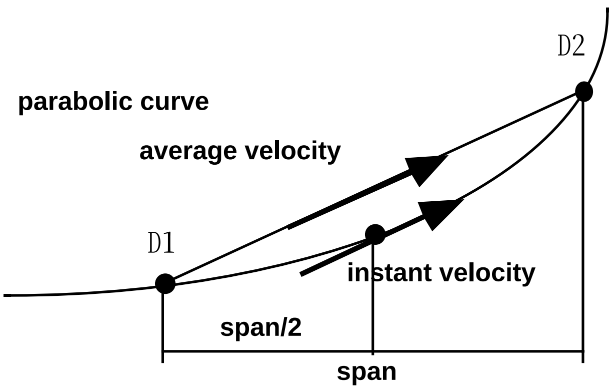

Figure 7. Average velocity gives instant velocity at the middle point

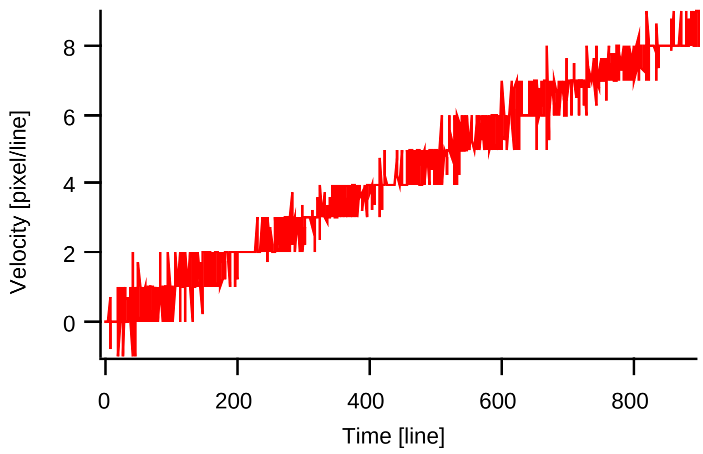

Figure 8. Variation of velocity as time

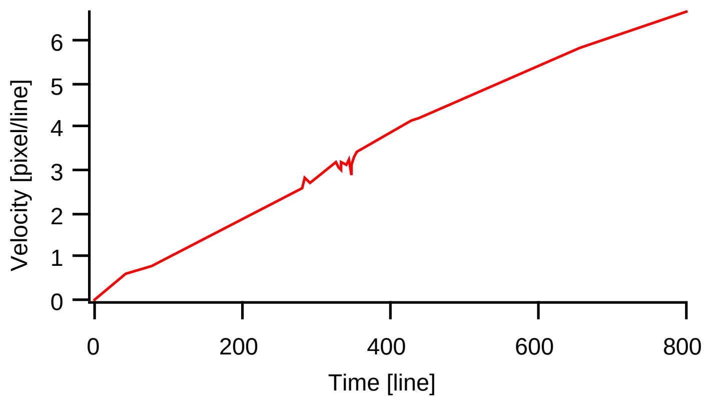

Figure 9. Variation of velocity calculated from suitable two-line selection

But making d-value table is very time consuming task, any kind of parallel processing or distributed processing should help system's performances. In this paper network distributed system is proposed. Basic concept or scheme is showed in Fig. 10. This system consists of various performance computers and one supervising host. Systems can talk each other by RPC through Ethernet (TCP/IP). So various ranges of OS can attend this system. Rough flow of processing procedure is on the figure.

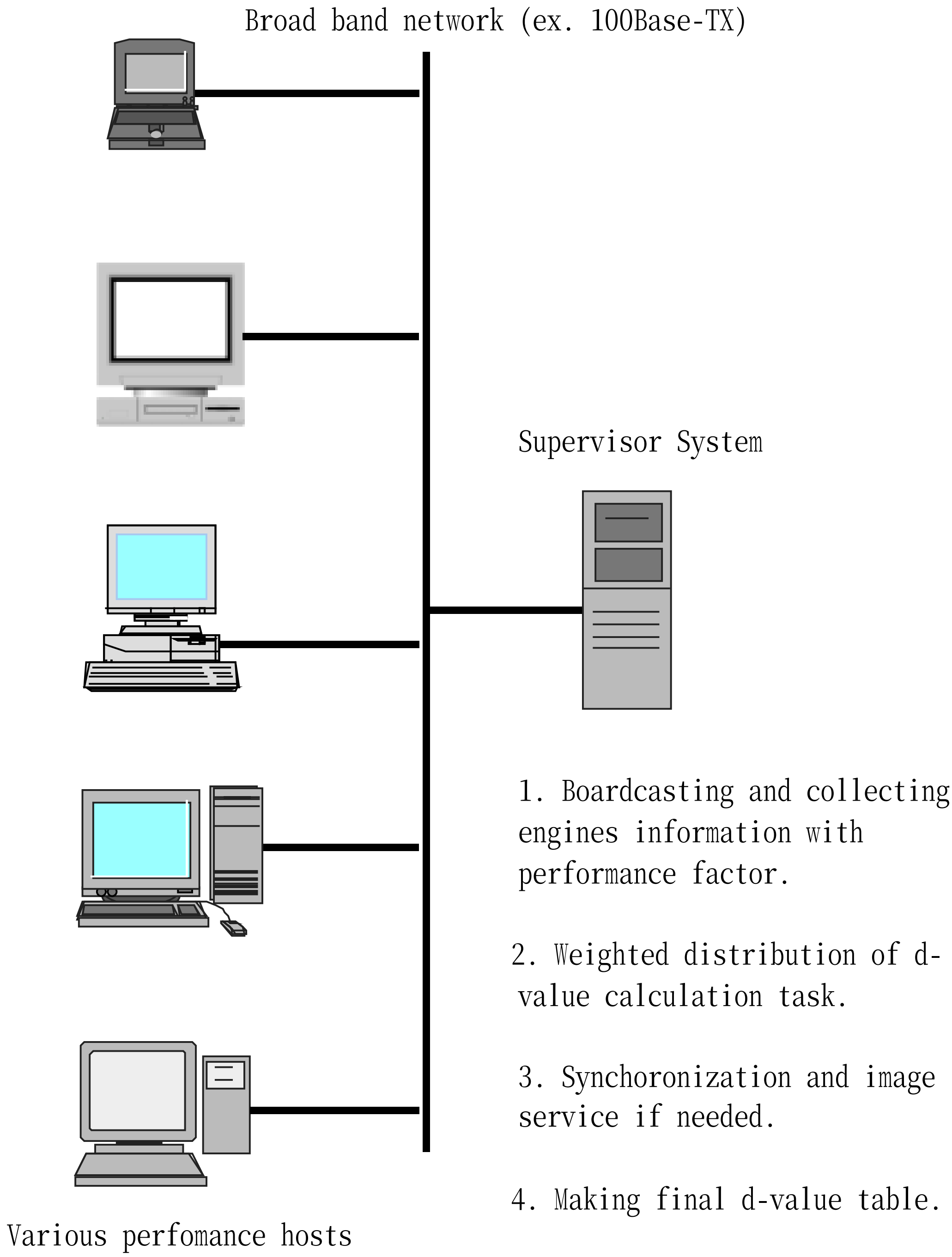

Figure 11. Rough schematic of networked distributed d-value processing system

4. CONCLUSION

Fully automatic analysis method of position detection with LSC was proposed. To estimate object displacement, d-value was introduced and its validity was proved experimentally. In addition, by selecting suitably separated two points, resultant velocity at middle point can be much accurate than direct differentiation of time-displacement data. Thus time-velocity analysis based on minimum d-value searching method is proved to be effective by experiment this time. But prior to that, complete d-value table should be calculated. And it is very time-consuming task. So a network distributed d-value calculation system was proposed.

REFERENCE

1. 1. N. Yokoyama: Position detection by cross-correlation with linear scan camera (one-dimensional high-speed video camera), Int. J. Japan Soc. Prec. Eng., Vol. 33, No.1 (Mar. 1999) 57-58