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OPTICAL TOMOGRAPHY: REAL-TIME VELOCITY PROFILE MEASUREMENT USING PIXEL-TO-PIXEL VELOCITY METHOD

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Abstract The cross-correlation function usually takes a long computation time, so it is quite hard to produce a velocity profile in a short time especially in online mode. Thus, data distribution system is developed by using multiple data processing units and concept of parallel data processing to speed up the process of producing velocity profile. This paper also presents the configuration of new data processing system and how it can replace single processing unit to compute velocity profile faster.

Keywords: Velocity profile; cross-correlation function; data distribution system

Abstrak Fungsi korelasi-rentas kebiasaannya memerlukan masa pengiraan berkomputer yg panjang, maka ia agak sukar untuk menghasil profil halaju dalam masa yang singkat terutama sekali dalam mod masa-nyata. Oleh itu, system pengagihan data dibangunkan dengan menggunakan unit pemprosesan data berganda dan konsep unit pemprosesan data selari untuk mempercepatkan proses penghasilan profil halaju. Penulisan ini juga membentangkan konfigurasi system pemprosesan data yang baru dan bagaimana ia beleh menggantikan unit pemprosesan tunggal untuk mengira profil halaju dengan lebih pantas.

Kata kunci: Profil halaju; fungsi korelasi-rentas; sistem pengagihan data

1.0 INTRODUCTION

Since process tomography is successfully applied in measurement of volumetric concentrations of solids, many researches have been carried out to obtain the flow

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velocity for pneumatic conveying system. In the research by Mohd Fua'ad (Mohd Fua'ad, 1996), an offline mode of velocity profile measurement for the flow system is developed using electrical charge tomography [1]. Later, the real-time implementation of the system has been done by (Mohd Hezri, 2002).

To produce a velocity profile, large numbers of calculations are involved because a cross-correlation function requires sufficient time-series data (typically more than 100) to be developed [2]. The research carried out by (Mohd Aznanshah, 2002) has proven that optical sensor in tomography system is able to measure the velocity of solid flow in gravity flow rig. For a single velocity result using 312 time-series of data in CCF calculation, it requires 985ms to complete the process [3]. It is crucial to note that the velocity profile of this project is constructed by 16x16 pixels velocity results, thus it takes a quite long data processing time based on this time result. It serves as the main problem during real-time mass flow rate determination that using this profile. As a result, parallel data processing technique is applied in this project to solve this kind of problem.

2.0 CROSS-CORRELATION FUNCTION

Correlation is a statistical technique that familiar used in industrial flow measurement to measure the degree of similarity between two signals and it working in time domain environment. Cross-correlation represents the relationship between two signals measured at two points in space and at two different times [4]. It provides information about the similarity between two time-series signals in a particular time delay.

The cross-correlation function of two sets of random data *x(t)* and *y(t)* describes the general dependence of the values of one set of data on the other. This function can be expressed by using equation 1 and 2. The equation 1 is in the continuous time domain, whereas equation 2 is in the discrete time domain.

$$Rxy(\tau) = \lim_{\tau \to \infty} \frac{1}{T} \int_0^T x(t) y(t+\tau) dt \text{ ; For } \tau \geq 0 \qquad (1)$$

$$Rxy(\tau) = \frac{1}{N}\sum_{n=0}^{N-1} x(n)y(n+\tau)dt \quad ; \text{For } \tau \geq 0 \qquad (2)$$

$R_{xy}(\tau)$ is always in real values, which may be either positive or negative. It does not necessarily has a maximum value at $\tau = 0$. To apply this function, two random signals, $x(t)$ and $y(t)$ must have the property that retain the fundamental and only those harmonics which are present in both processes together with their phase difference. Otherwise, function $R_{xy}(\tau)$ will result 0 in all values of τ. This also means that $x(t)$ and $y(t)$ are uncorrelated or statistically independent [4].

The basic principle of cross-correlation flow measurement is that some patterns of material flow inside the conveyor travel without distortion between the upstream sensor and downstream sensor within an acceptable distance between the sensors. Thus the velocity of flow is given by:

$$v = \frac{D}{\tau^*} \qquad (3)$$

Where v is the flow velocity, D is the distance between sensors and τ^* is the value of τ corresponding to the peak value of $R_{xy}(\tau)$ [4].

3.0 PIXEL-TO-PIXEL VELOCITY METHOD

Velocity profile is determined based on pixel-to-pixel velocity method. First, at least one hundred concentration profiles of upstream sensor and downstream sensor are collected. Next, each pixel inside the upstream profile will cross-correlate with the same pixel that is located in downstream profile, resulting in a time delay. The distance in between both sensors is then used to divide the time delay of each pixel to obtain the velocity of the corresponding pixel in velocity profile. Figure 1 shows the way to determine the velocity of pixel (S_3, S_{22}) in velocity profile.

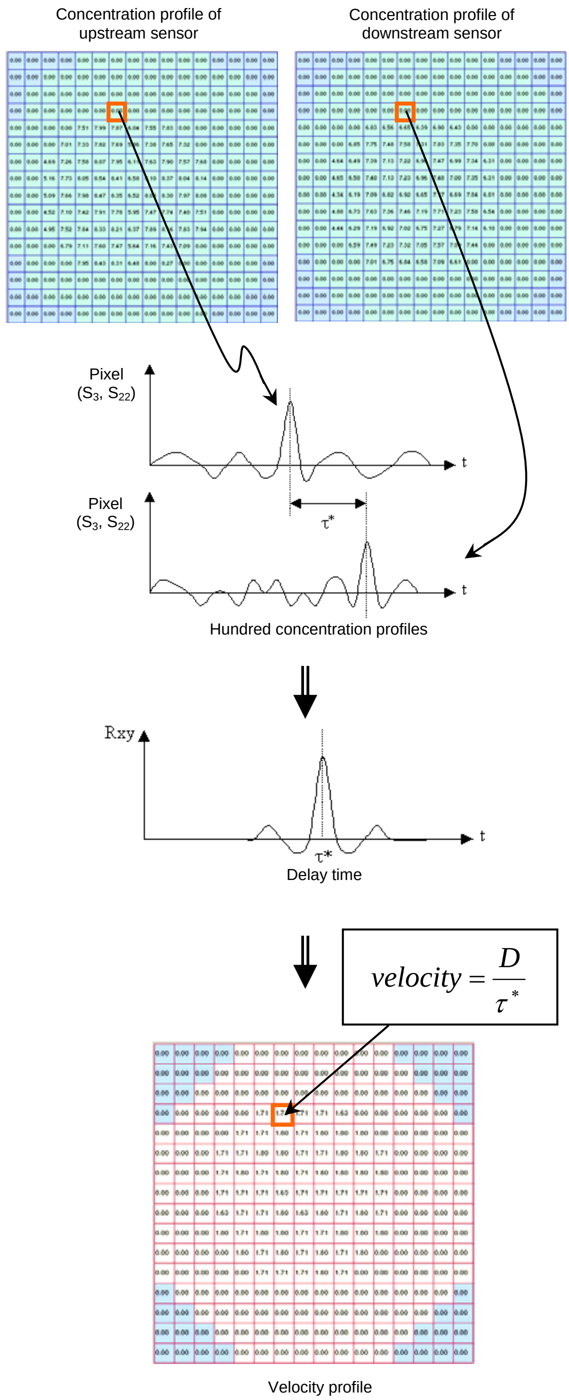

Figure 1 The way for obtaining velocity of pixel (S_3, S_{22}) in velocity profile

4.0 SINGLE PROCESSING UNIT

The velocity profile measurement using single processing unit is a general system that widely used for the process tomography. The hardware configuration of this project is shown in Figure 2. There are two optical tomography sensors that located at upstream and downstream respectively with a distance of 42 mm.

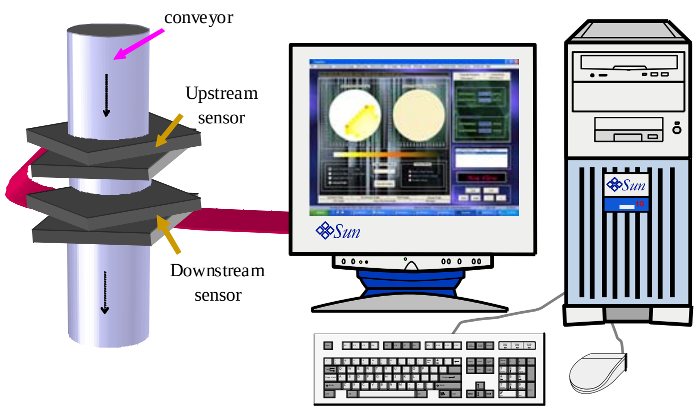

Figure 2 Configuration of single processing unit system

By using this configuration of system, the corresponding process flow timing structure is shown in Figure 3. From the observation, one frame of process is start from x set data capturing (1 set of data consists of 156 readings), computes the x upstream and downstream concentration profiles, and finally calculates velocity profile and displays it on screen.

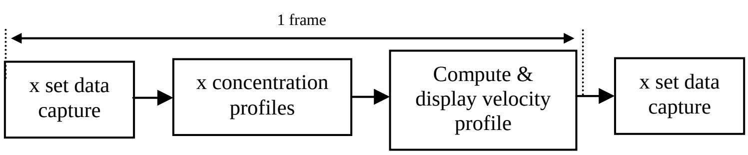

Figure 3 Flow timing structure for single processing unit in velocity measurement system

5.0 DATA DISTRIBUTION SYSTEM

This system uses multiple processing units to replace single processing unit in Figure 2. Two PCs are used, namely PC1 and main PC. Both PCs communicate with each other through the local area network that setup for them. The establishment of 2 PCs network is using WinSock programming function. All relevant steps are shown in the flow diagram of Figure 4. The flow diagram explains the process performed by PC1 and main PC to set up a connection for data exchange in network using TCP reliable data delivery's protocol. Practically, two computers are very difficult to run programs at the same time; therefore program in main PC starts before PC1. Without user's interruption, program will create UDP and TCP sockets automatically. Next, TCP socket stays in listen mode whereas UDP socket stays in receive mode. Another socket of UDP will broadcast an argot. The argot used is 'TN' with the purpose to give opportunities to other PCs make TCP connection to the broadcaster if a match occurs. It is imperative to allow such establishment when two or more data distribution systems are constructed in the same local area network because all systems' operation will not crash with one another. Since UDP socket of PC1 is not operating in receive mode during broadcasting of main PC, PC1 is unable to make TCP connection to main PC. Conversely, when PC1 broadcasts the argot, UDP socket of main PC is in receive mode and enabling main PC to make a TCP connection to PC1. TCP socket of PC1 will accept the connection because it always stays in listen mode. Finally, 2 PCs system is established and ready for data exchange in measurement process.

The hardware configuration of this network system is shown in Figure 5. All PCs will link to a switch via UTP cable. One end of the cable connects to the RJ45 socket on the NIC of PC and the other end connects to the socket provided by switch. Only the main PC will connect to display unit (monitor). The PC1 of the system has the function to capture data from optical tomography sensors via the DAS card that is plugged into the PC. The main PC computes the upstream and downstream concentration profiles for next process of velocity profile calculation using cross-correlation function. The whole process flow timing structure is presented in Figure 6. One frame of process starts with PC1 captures data from sensors, then compiles the data to the corresponding format and sends to main PC. The process is finishing when main PC successfully receives data, produces concentration profiles, computes velocity profile and displays it onto display unit.

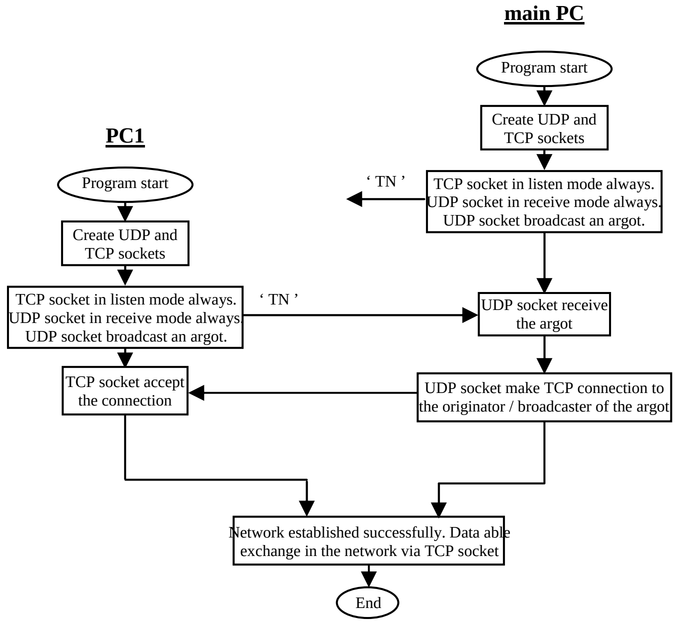

Figure 4 Flow diagram for network establishment in 2 PCs data distribution system

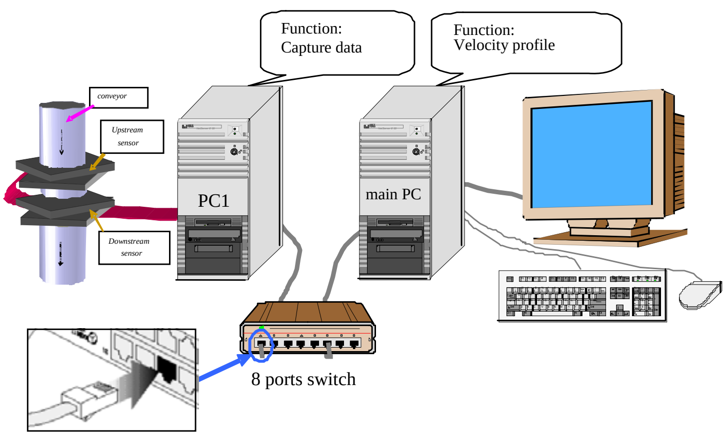

Figure 5 Hardware configuration of data distribution system in velocity profile measurement

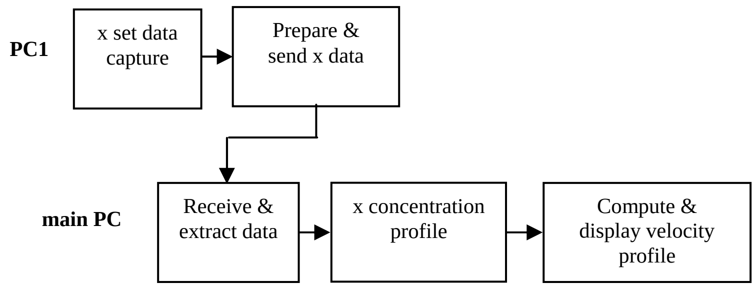

Figure 6 Process flow timing structure for data distribution system in velocity measurement system

6.0 RESULTS

To compare the performance of velocity measurement system by using single processing unit and multiple processing unit, the velocity profile refreshing rate is used. This refreshing rate is computed from one over the total processing time per frame. The performance of this system mainly depends on the amount of data used in the cross-correlation computation. The greater number is used, the lower velocity profile refreshing rate is obtained.

By using single processing unit in the system, the measured velocity profile refreshing rates in real-time mode are shown in Figure 7. The refreshing rate is decreasing dramatically when time-series of data is in increasing. It is because the greater amount of time-series input signals for cross-correlation function, the longer time is needed for correlating both input signals. The results obtained by using data distribution system are illustrated in Figure 8.

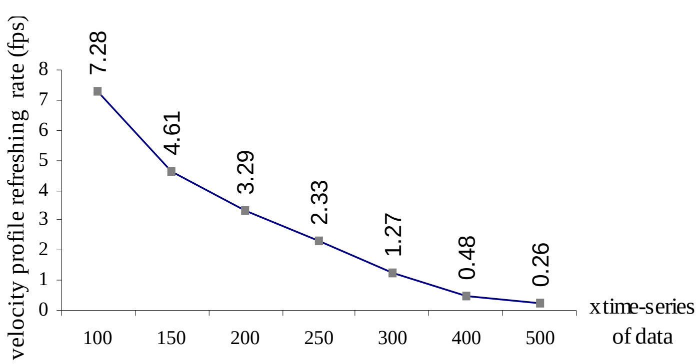

Figure 7 Velocity profile refreshing rates using single processing unit

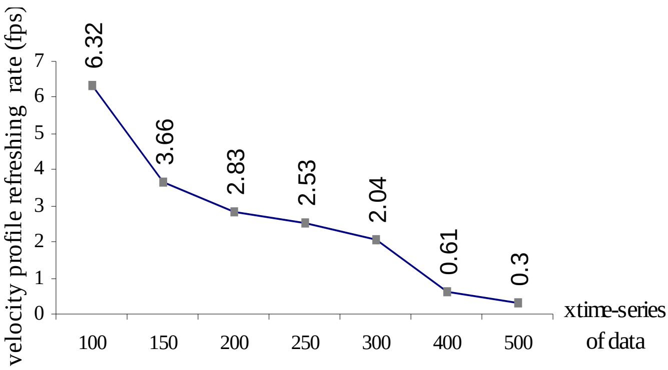

Figure 8 Velocity profile refreshing rates using multiple processing units

The corresponding computer utilization in data distribution system is shown in Table 1. Basically, the rule of using data distribution system is based on the data processing time that must be much greater than the data transfer time including data formatting and extracting time. Besides, the %utilization of computers used in the data distribution system is also a crucial element. If the %utilization of a PC in data distribution system is low, the parallel data processing method is unable to work successfully because the PC contains a little task to be computed whereas the other PCs have much more tasks to be done. The system achieves optimisation when all PCs within data distribution system have the %utilization near to 100%.

Table 1 The percentage utilization of PCs in data distribution system

x Set of Data	% Utilization	
	PC1	Main PC
100	100.00	14.77
150	100.00	16.61
200	100.00	20.69
250	100.00	36.41
300	100.00	94.53
400	38.42	100.00
500	24.25	100.00

7.0 SYTEM IMPROVEMENT

Compare the graph in Figure 7 and 8, it can be noticed that multiple processing units has the capability to improve the performance achieved by using single processing unit in the velocity measurement system. The percentage improvements of all cases are shown in Figure 9. Real-time data distribution system can only speed up the measurement process at x equal to 250 and 300. It is because all PCs utilization of these two cases are sufficient to perform parallel data processing. The system achieves optimisation at x = 300 and the %utilization of both PCs are 100% and 94.53% respectively. For x = 100, x = 150 and x = 200; no improvement obtained by using the data distribution system. For these cases, the parallel data processing is unable to save processing time because the %utilization of main PC is too low. The data distribution system shows improvement if at least 250 set of data are used. The maximum improvement occurs at x = 300, which is 60.63%. After achieving the peak of improvement, decrement begins in the data distribution system.

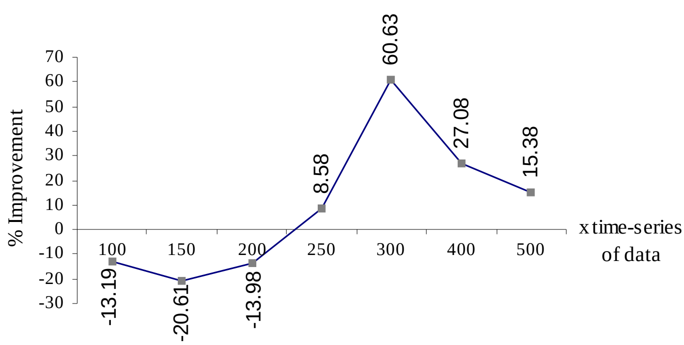

Figure 9 The %improvement of velocity profile refreshing rate by using data distribution system

8.0 CONCLUSION

Data distribution system has the ability to replace the single processing unit in the velocity measurement system for obtaining better performance in real-time measurement. As long as the measurement in the right setting, it can speed up the process to produce velocity profile.

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