

Optical Tomography: Real-time Mass Flow Rate in Solid Gas Measurement

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ABSTRACT

This paper describes how to combine a network system and a tomography system to obtain mass flow rate result by using parallel data processing technique in online mode. The new system is investigated to reduce the data processing time and produce as many as mass flow rate results per second. The knowledge of concentration profile and velocity profile for cross-section of the pipeline are needed to generate a mass flow rate profile, in which the proportional result is used to determine the mass flow rate.

Keywords: real-time, mass flow rate, network system

1. Introduction

Nowadays, Pneumatic transportation of bulk solids is getting more and more important in many industries, therefore the mass flow rate has become a valuable parameter in this case. The direct measurement method of solids mass flow rates includes thermal method, active charging and detecting methods, and passive charge detecting method [1]. However, these methods have their own limitations such as unsuitable for applications in which fast dynamic responses are essential, poor repeatability and particle charging using a high voltage source (100 – 500 V).

Since process tomography is successfully applied in measurement of volumetric concentrations of solids, many researches have been carried out to prove that process tomography has the ability to do measurement of solids mass flow rates. Works done by Ruzairi [2] show that optical fibre sensor is applicable in flow visualization (image reconstruction), mass flow rate estimation and particle sizing measurement for pneumatic conveying system. For the mass flow rate estimation, it can be determined by combining both concentration and velocity profile [3].

1.1 Optical tomography sensor

There are two optical tomography sensors designed for this measurement system. One is located at upstream and one is located at downstream. The distance in between them is 42 mm. For each tomography sensor, it uses parallel beam projection geometry, infrared light source and contains resolution of 16x16 pixels. Both of the sensors provide 156 readings to be captured by processing unit as one set of data.

1.2 Concentration profile

Concentration profiles of upstream and downstream sensors are produced after applying the image reconstruction algorithm. The algorithm used in this project is Hybrid image reconstruction algorithm that proposed by (Sallehuddin, 2000) [4]. After convert the values within the concentration profiles to correspond color, the upstream and downstream cross-sectional images can be obtained.

1.3 Velocity profile

Velocity profile of this system is determined based on pixel-to-pixel velocity method. First, collect at least one hundred or more concentration profiles of upstream and downstream tomography sensors. Next, each pixel inside the upstream profile will cross-correlate with the same pixel that is located in downstream profile result 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.

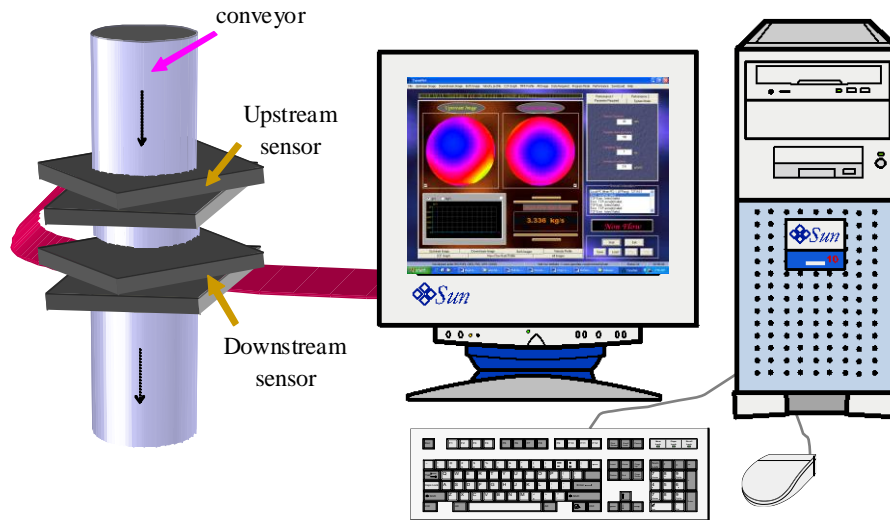


Figure 2. Configuration of single processing unit system

4. Data distribution system

Data distribution system is a local area network that using multiple processing unit to replace single processing unit in the measurement system. The hardware configuration of it is shown in Figure 3. There are three computers within the system and labelled PC1, PC2 and mainPC respectively. PC1 is used in the process of data capture; PC2 calculates velocity profile and mass flow rate result; mainPC displays cross-sectional images of both upstream and downstream sensors and mass flow rate result. Only mainPC will connect to display unit, keyboard and mouse compared to other. It is because the program written for mainPC will control PC1 and PC2 through network.

To connect all computers in the system, networking programming (WinSock) is used and the procedures are shown in flow diagram of Figure 4. The program in mainPC is run first, followed by PC1 and finally PC2. The program will automatically create UDP and TCP sockets. TCP socket will always be in listen mode whereas UDP socket will always in receive mode. Next, the other UDP socket broadcast an argot once only. The broadcasting of mainPC gets not response because both PC1 and PC2 are still not ready to receive the message at the time. After PC1 broadcasts the argot, mainPC will receive it and make TCP connection to PC1, but PC2 will miss it since UDP socket of PC2 is still not in receive mode at that time. When PC2 is broadcasting, the other UDP sockets of PC1 and mainPC are already in receive mode. Therefore, PC1 and mainPC will make TCP connection to PC2 after receiving the argot. Now, all PCs are connected to one another and are able to exchange data for subsequent process.

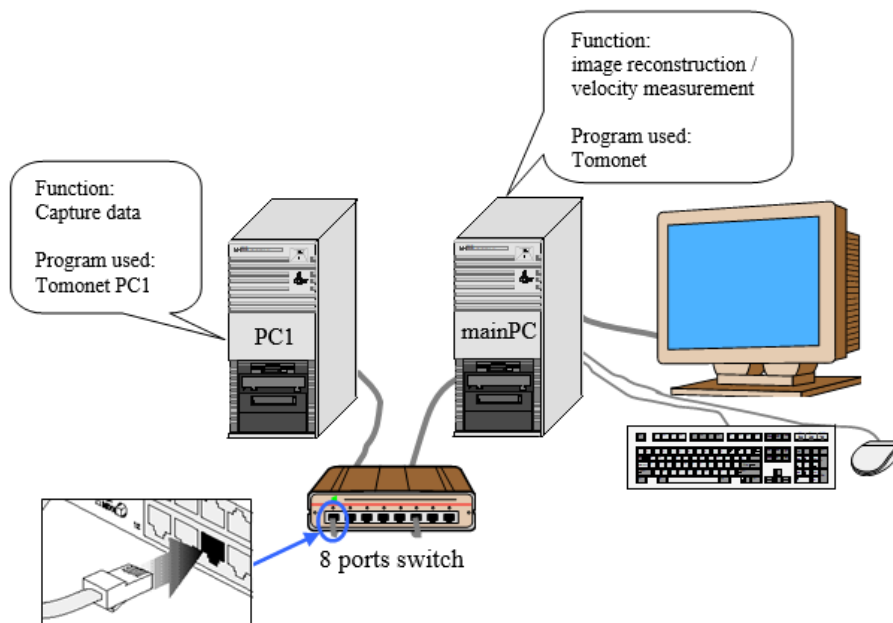


Figure 3. Hardware configuration of data distribution system in mass flow rate measurement system

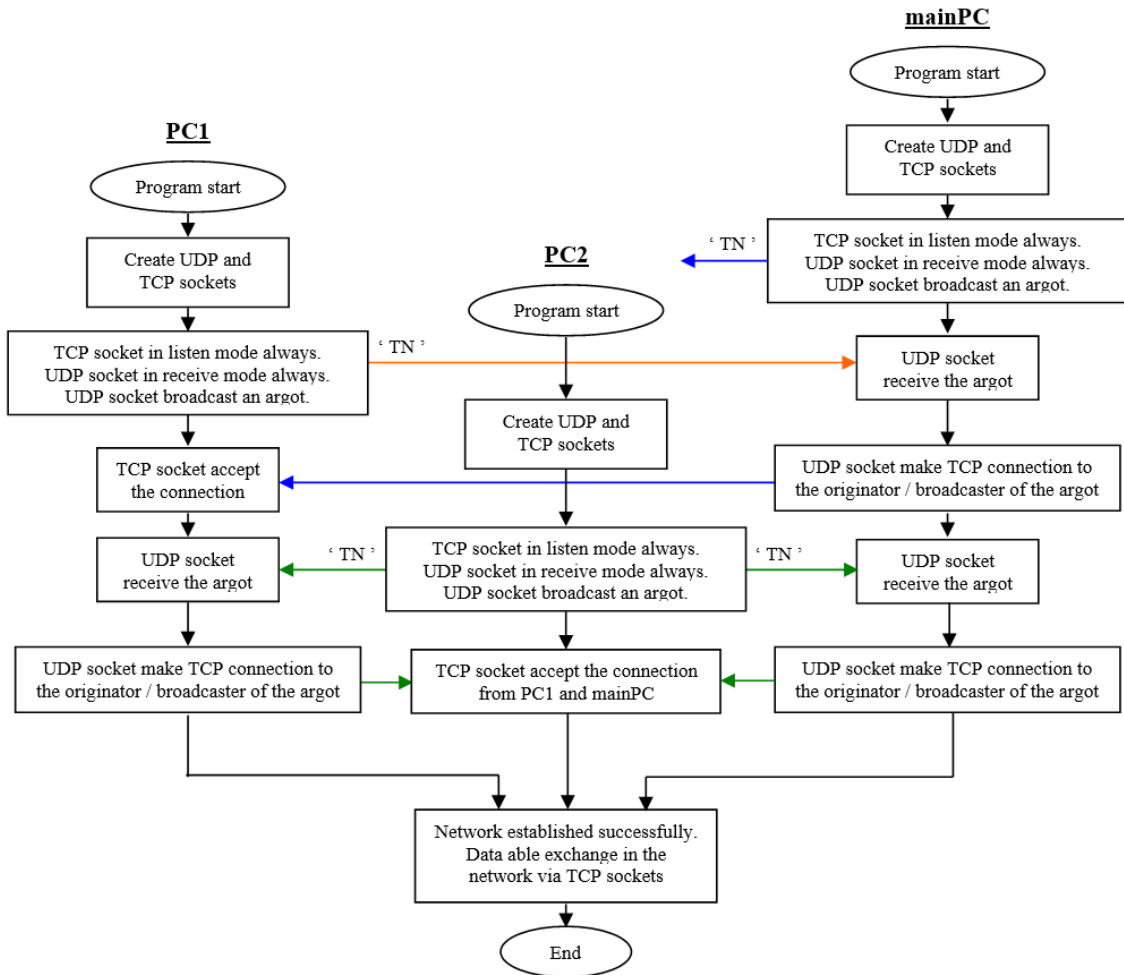


Figure 4. Flow diagram for network establishment in data distribution system

The process flow timing structure of data distribution system is presented in Figure 5. One frame of process starts with PC1 captures data from tomography sensors, compiles to the corresponding format and sends to PC2 and mainPC. PC2 will receive the data, compute concentration profiles, velocity profile, mass flow rate result and send it to mainPC. mainPC will reconstruct images from the data received and display the mass flow rate result received onto screen.

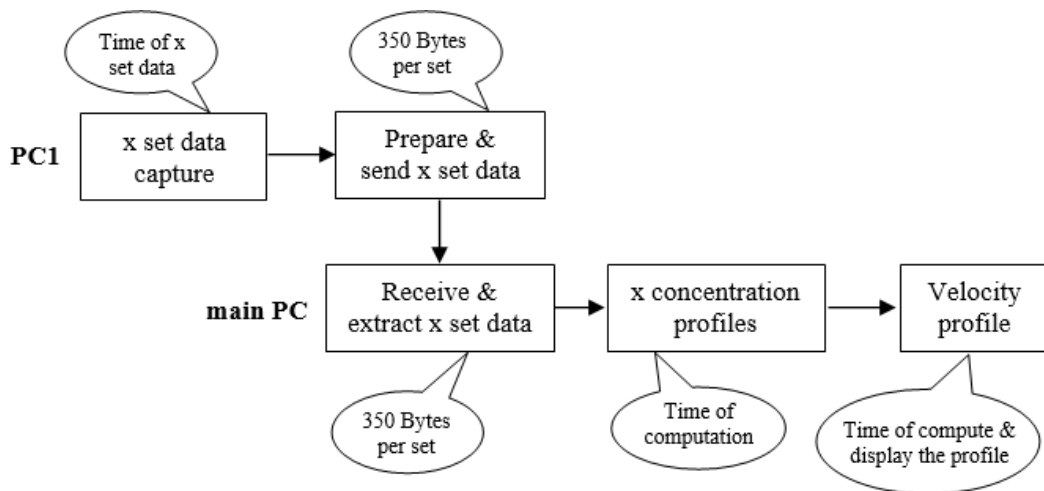


Figure 5. Process flow timing structure using data distribution system

5. Results

The performance of real-time single processing unit system and data distribution system can be investigated by setting the image resolution of tomogram and x time-series of data to be used for calculating velocity profile. The mass flow rate refreshing rate is measured for both systems. This refreshing rate is based on how many mass flow rate results can display onto screen per second. It is computed by using one over the total processing time per frame. The corresponding unit is frames per second (fps).

The measured results of mass flow rate refreshing rate using single processing unit are shown in Figure 6. When no image is displayed in the system, the MFR refreshing rate obtained is equal to the maximum refreshing rate that can be achieved. So, the maximum refreshing rate for $x = 100$, $x = 200$ and $x = 300$ are 7.27 fps, 3.31 fps and 1.25 fps respectively. On the other hand, the greater number of x used in the measurement, the lower the MFR refreshing rate procured. It is because the corresponding case requires longer data processing time in cross-correlation computation.

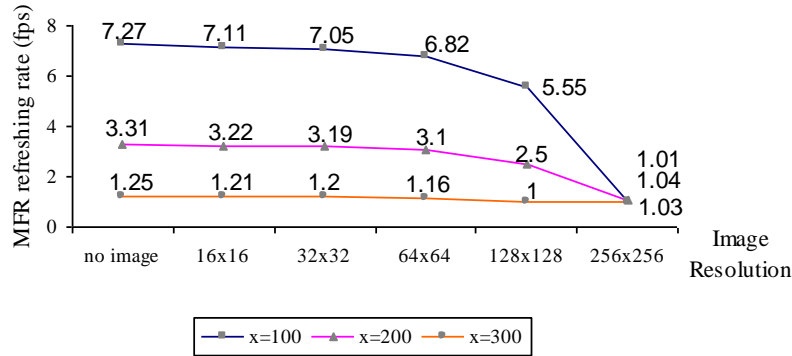


Figure 6. Measured image refreshing rate using single processing unit

By using data distribution system (multiple processing units), the mass flow rate refreshing rate results are illustrated in Figure 7. As can be seen from the graph, the MFR refreshing rate when no images are displayed are 6.29 fps at $x = 100$, 3.14 fps at $x = 200$ and 1.77 fps at $x = 300$. For the MFR refreshing rate in the same number of x , the results of all corresponding cases are approximately the same.

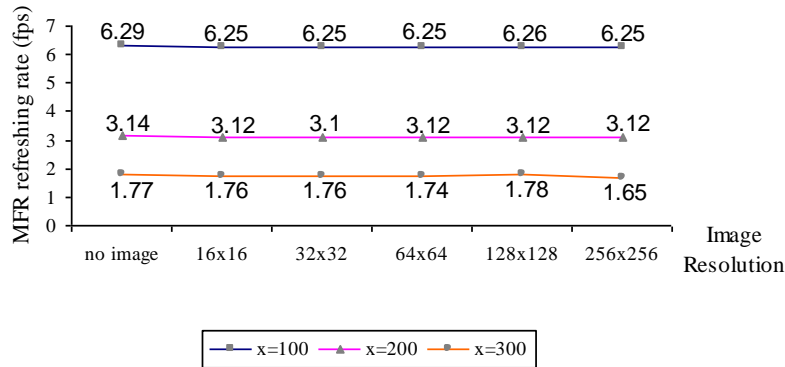


Figure 7. Measured image refreshing rate using multiple processing unit

Each PC in the data distribution system has its own %utilization as shown in Table 1. It is computed by summing all processes time of the relevant PC and is divided by the total time per frame. The data distribution system achieves the optimization in the case of 256x256 pixels resolution and $x = 300$ because all of the PCs have high utilization, which are 84.89%, 94.96% and 96.48% for PC1, mainPC and PC2 individually.

Table 1. The percentage utilization of PCs in data distribution system

Image resolution	x set of data	% Utilization		
		PC1	mainPC	PC2
No image	100	100.00	0.17	15.01
	200	100.00	0.09	23.31
	300	86.96	0.05	100.00
16x16	100	100.00	2.24	14.88
	200	100.00	2.41	23.08
	300	87.99	2.47	100.00
32x32	100	100.00	2.79	14.88
	200	100.00	3.03	23.08
	300	87.99	3.12	100.00
64x64	100	100.00	6.00	14.88
	200	100.00	6.64	23.08
	300	87.99	6.87	100.00
128x128	100	100.00	19.76	14.88
	200	100.00	22.10	23.08
	300	87.99	22.96	100.00
256x256	100	100.00	84.27	14.88
	200	99.47	94.09	22.95
	300	84.89	94.96	96.48

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 optimization when all PCs within data distribution system have the %utilization near to 100%.

6. System improvement

To compare the single processing unit results with the multiple processing unit results, the statistical results obtained are illustrated in Figure 8. From the observation, notice that the maximum improvement of MFR refreshing rate occurs at the resolution of 256x256 and x = 100, which is 518.81%. For x = 100 and x = 200, the %improvement start with negative values. After applying the resolution of 128x128, they increase dramatically. If x = 300, positive improvement will be obtained and it shows a quite stable increment. The maximum peaks of %improvement of these x sets of data are 518.81%, 200% and 78% respectively.

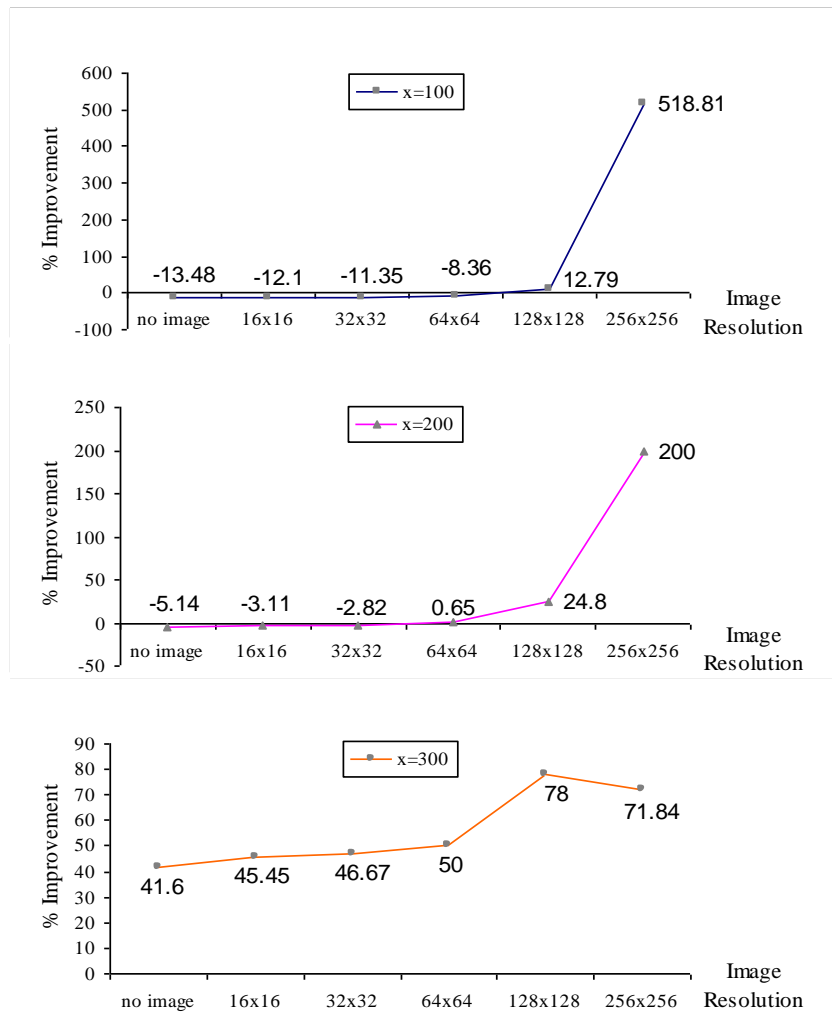


Figure 8. Percentage improvement of mass flow rate refreshing rate by using data distribution system

7. Conclusions

Data distribution system is able to improve the MFR refreshing rate obtained from the single processing unit system. It means that the data distribution system can speed up the data processing time by using parallel data processing technique. However, it is only true for the right setting in the selection of image resolution and the x time-series of data to be cross-correlated. Otherwise, data distribution system will impair the performance of existing system. By using the same concept, data distribution system also has the potential and capability to speed up any kind of system that has critical processing time either in process tomography or other field.

8. References

- [1] Yong Yan (1996). Mass Flow Measurement of Bulk Solids in Pneumatic pipelines. *Meas. Sci. Technol.* Vol 7: 1687-1706.
- [2] Ruzairi Abdul Rahim (1996). *A Tomography Imaging System For Pneumatic Conveyors Using Optical Fibres*. Sheffield Hallam University. Ph.D. Thesis.
- [3] Azrita Binti Alias (2002). *Mass Flow Visualization Of Solid Particles In Pneumatic Pipelines Using Eletrodynamic Tomography System*. Universiti Teknologi Malaysia. M.Sc. Thesis.
- [4] Sallehuddin Ibrahim (2000). *Measurement Of Gas Bubbles In A Vertical Water Column Using optical Tomography*. Sheffield Hallam University. Ph.D. Thesis.