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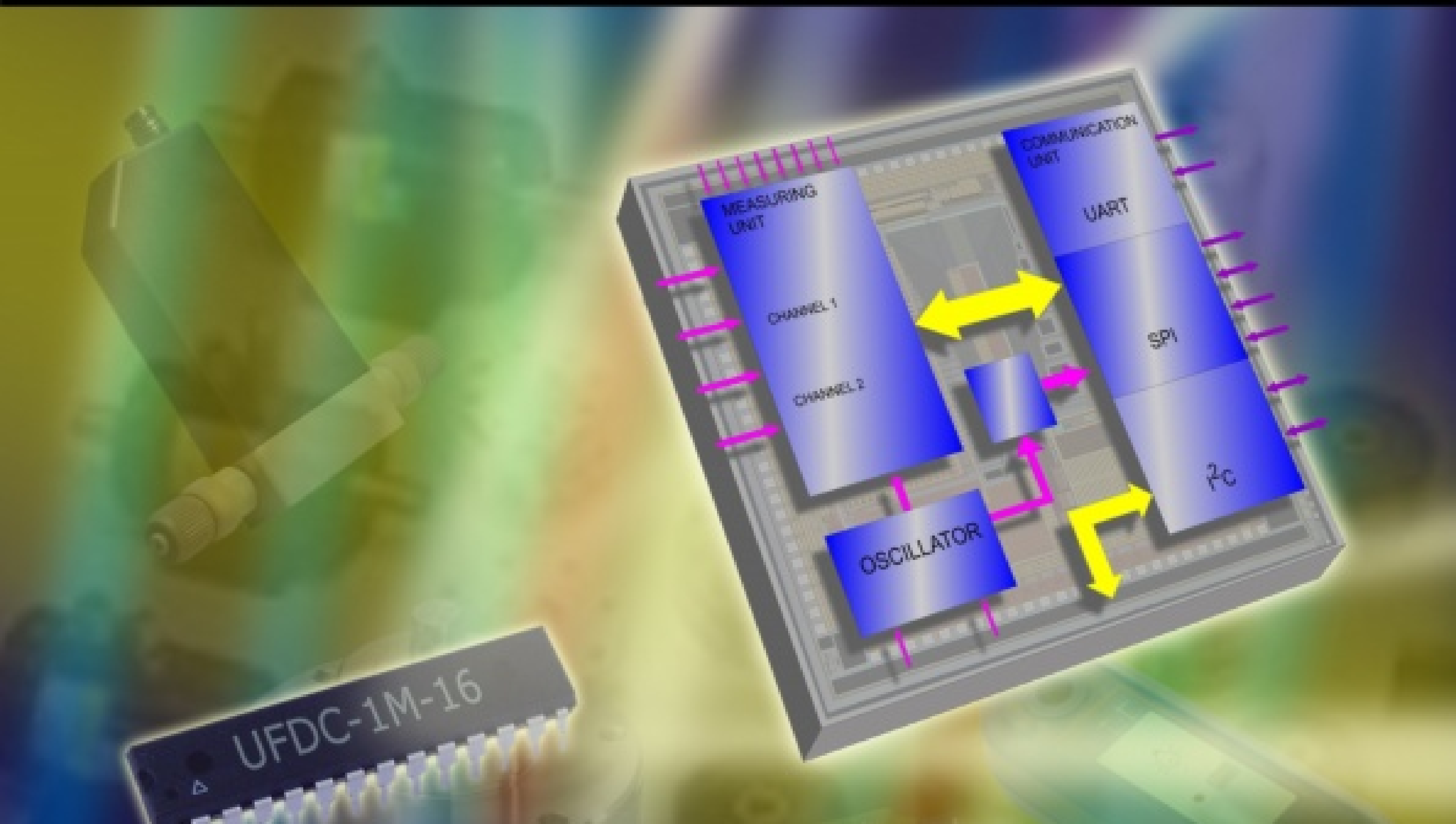

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Infrared Tomography: Data Distribution System for Real-Time Mass Flow Rate Measurement

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Abstract: The system developed in this research has the objective of measuring mass flow rate in an online mode. If a single computer is used as data processing unit, a longer time is needed to produce a measurement result. In the research carried out by previous researcher shows about 11.2 seconds is needed to obtain one mass flow rate result in the offline mode (using offline data). This insufficient real-time result will cause problems in a feedback control process when applying the system on industrial plants. To increase the refreshing rate of the measurement result, an investigation on a data distribution system is performed to replace the existing data processing unit. *Copyright © 2007 IFSA.*

Keywords: Mass flow rate, Data processing, Real-time, Data distribution system

1. Introduction

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 Chan (2004) & Green et. al (1997) [1], [9] show that optical fibre sensor is applicable in flow visualization (image reconstruction), mass flow rate estimation and particle sizing measurement for pneumatic conveying system. In the research by Mohd Fua'ad (1996) & Green et al (1997a) [10], [2], an offline mode of velocity profile measurement for the flow system is developed using electrical charge tomography. Later, the real-time implementation of the system has been done by Mohd Hezri (2002) [3]. For the mass flow rate estimation, it can be determined by combining both concentration and velocity profiles [4]. Hence, the main objective of this research is to measure solids mass flow rates in real-time mode using optical sensor.

To produce a velocity profile, large numbers of calculations are involved because a cross-correlation function requires sufficient time-series of data (typically more than 100) to be developed [3]. In this research, the velocity profile (16x16 pixels) is generated using pixel-to-pixel velocity method and not sensor-to-sensor velocity method. The previous research showed that to obtain velocity profile (11x11 pixels) from pixel-to-pixel velocity method using 312 time-series of data, the time needed is more than 2 seconds. This long processing time serves as the main problem during real-time mass flow rate determination. As a result, parallel data processing technique is applied in this research to solve this kind of problem.

In tomography system, mass flow rate measurement can be determined using two types of techniques. The first technique uses inverse solution of concentration measurement. The concentration profiles for various flow rates under the same condition are measured and stored as reference values for those flow rates. Then, these calibration results will be plotted into a graph. During the measurement for an unknowns flow rate, the concentration measurement result will be compared to the graph and inverse solution is applied to obtain the unknown flow rate. In the research by Chan (2002) [1], this kind of method was successfully applied to the mass flow rate measurement of solid particles (plastic beads) in a gravity flow conveyor. Nevertheless, this technique has some limitations like the error during varying environment conditions, sensors' signals saturation during dense flow, redoing the calibration whenever flow rate of a new material is measured and error occur during calibration process [7].

The second technique uses algorithm equation. The mass flow rate through any pixel P_{ij}, in the measurement cross section depends on the instantaneous concentration associated with the pixel C_{ij}, multiplied by the velocity associated with any pixel V_{ij} [2]. Then, the mass flow rate (MFR) through the measurement section is given by

$$MFR(g/s) = k \sum_{i=1,\, j=1}^{i=n,\, j=n} C_{ij} V_{ij} \tag{1}$$

where, C is the concentration expressed in volt (V), V is velocity in meter per second (ms^{-1}), n is the number of pixels in the measurement cross section and k is a calibration constant in gram per volt per meter ($gV^{-1}m^{-1}$). This equation was applied in the electrical charge tomography. Azrita (2002) [4] has successfully used this method to measure MFR in the offline mode and the total time to produce one MFR result is about 11.2 seconds. This technique is a novel approach in optical tomography. In this research, some modifications to the equation above are made to produce instantaneous mass flow rate result using optical tomography sensor.

In process tomography, the more critical part is to determine the velocity profile because a heavy calculation task is involved. The research carried out by Leong (2004) [5] 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 [6]. It is crucial to note that a velocity profile is constructed by 256 velocity results, thus it takes a quite long data processing time. To overcome this problem, C++ language is used in this research to process the data due to the fact that Visual C++ language can execute the program from 10 to 100 times faster than Visual Basic language. A simple test has been carried out by to compare the performance between Visual C++ 6.0 and Visual Basic 6.0. Two programs are written in two different programming languages but having to do the same task of calculating a 16x16 pixels velocity profile using 300 time-series of data. The result shows that Visual C++'s program uses 0.4s to complete the job while Visual Basic's program requires 4.3 s.

The data distribution system is a local area network (LAN) that uses Ethernet as the networking technology. It links a few computers together to create multiple data processing units. The concept of the new system is performing parallel data processing to increase mass flow rate result's refreshing rate. On the other hand, WinSock programming language as the networking programming language is used for communication among all computers in the network.

2. Image Reconstruction System

A general optical flow imaging system is constructed by using optical tomography sensor, signal measurement circuitry, data acquisition system, and a computer as data processing unit and display unit. The system that designed for this research is illustrated in Fig. 1.

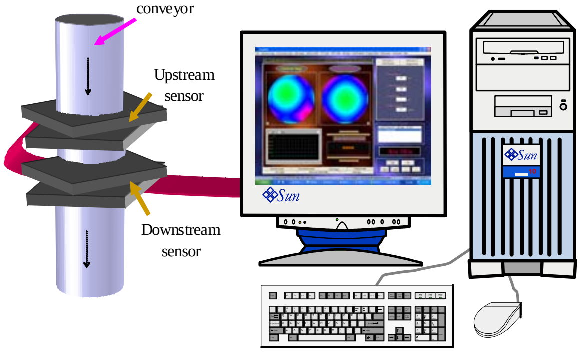
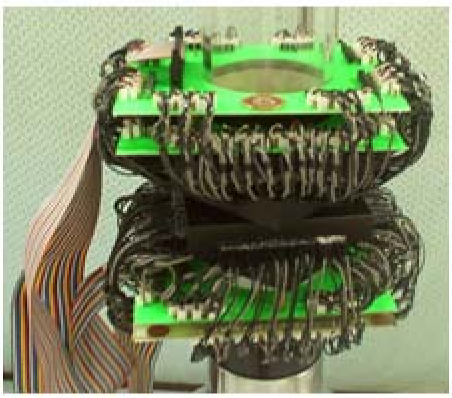
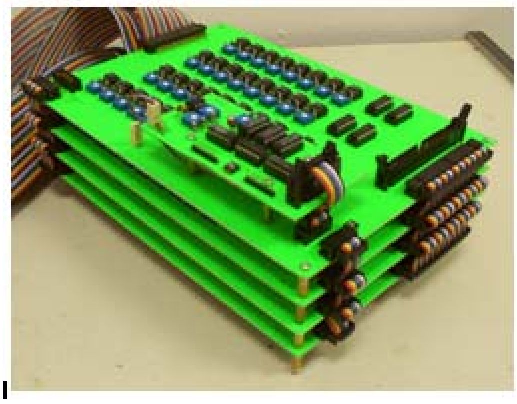


Fig. 1. General system configuration.

It can be noticed that there are two tomography sensors in this research, which are upstream sensor and downstream sensor. [8] Thus, the developed system will display two tomograms on the program written. Fig. 2 shows the optical tomography hardware that has been developed.



Optical tomography sensor



System circuits

Fig. 2. Optical Tomography Hardware System.

3. Type of System

Data distribution system of this research used three 3 PCs image reconstruction and mass flow rate measurement system. Each type of the data distribution system is investigated to see whether the results' refreshing rate of the corresponding measurement can be greater than the rate obtained by using single computer in the same measurement system for each application respectively. The architecture in each system is constructed by the hardware connection and network establishment for providing the environment of data exchanging among PCs in the network.

3.1 Three PCs Image Reconstruction and Mass Flow Rate Measurement System

The hardware configuration shown in Fig. 3. Three processors in the system are labeled 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.

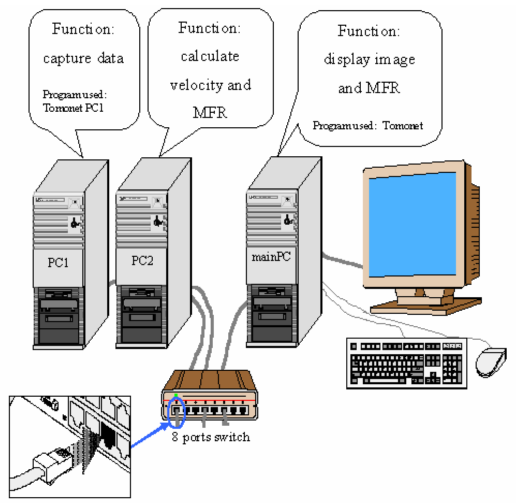


Fig. 3. Hardware connection in 3 PCs image reconstruction and mass flow rate measurement system.

The program in mainPC runs first, followed by PC1 and finally PC2. As usual, 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 no response because both PC1 and PC2 are still not ready to receive the message at that 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 in 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 processes.

4. Results

4.1 Real-time Mass Flow Rate Measurement in Vertical Pipeline Measurement

4.1.1 Real-time System Performance Test

A real-time system is said to be a high performance system if it can produce as many as results of measurement per second. In optical tomography, the measurement of mass flow rate by using pixel-to-pixel velocity method normally takes a few seconds to produce one result. So, it has low performance. In this research, data distribution system is investigated to improve the performance of real-time system. There are three kinds of application systems to be investigated, which are image reconstruction system, velocity measurement system, and image reconstruction with mass flow rate measurement system. For each system, the comparison between single processing unit system and data distribution system is done.

4.1.2 Image Reconstruction System

In this system, both upstream and downstream cross-sectional images will be displayed on the 'Both Images' page in TomoNet program. In addition, 5 types of image resolutions are available. The higher resolution to be viewed, the longer time will be used to process the images. By applying single processing unit in this system, the flow timing structure is shown in Fig. 4.

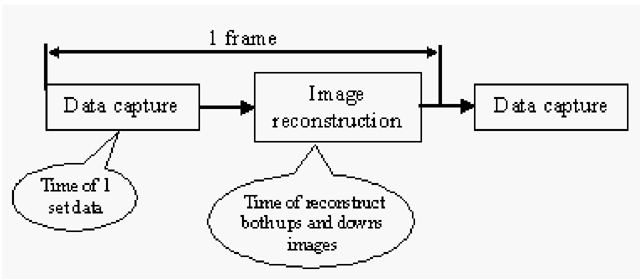


Fig. 4. Flow timing structure for single processing unit in image reconstruction system.

To estimate the image refreshing rate, all processes time in the timing structure are computed first by using high performance timer. Then, one over the summing all processing time will produce the image refreshing rate in the unit of frame per second (fps).

The measured image refreshing rate must be less than the predicted value because it covers all other execution time of programming codes that are located outside the process routine. Therefore, the refreshing rate computed is quite accurate and reliable. Table 1 tabulates the predicted and measured image refreshing rate in different resolutions.

Table 1. Image refreshing rate by using single processing unit in image reconstruction system.

Image resolution	Time of process (ms)		Total time per frame (ms)	Image refreshing rate		
	Data capture	Image reconstruction		Predicted (fps)	Measured (fps)	% different (meas-pred)
16x16	1.23	0.73	1.96	510.20	489.30	4.27
32x32	1.23	0.95	2.18	458.72	432.71	6.01
64x64	1.23	2.35	3.58	279.33	253.90	10.01
128x128	1.23	8.21	9.44	105.93	97.65	8.48
256x256	1.23	36.51	37.74	26.49	25.83	2.56

The data distribution system of this application uses 2 computers. The flow timing structure is shown in Fig. 5.

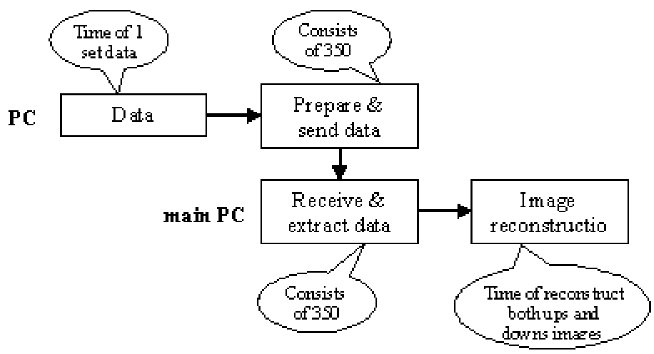


Fig. 5. Flow timing structure for 2 PCs image reconstruction system.

Table 2 shows the image refreshing rate by using data distribution system.

Table 2. Image refreshing rate by using 2 PCs image reconstruction system.

Image resolution	Time of process (ms)				Total time per frame (ms)
	In PC1		In mainPC		
	Data capture	Prepare & send data	Recv & extract data	Img reconstruction	
16x16	1.23	0.35	0.095	0.73	1.580
32x32	1.23	0.35	0.095	0.95	1.580
64x64	1.23	0.35	0.095	2.35	2.445
128x128	1.23	0.35	0.095	8.21	8.305
256x256	1.23	0.35	0.095	36.51	36.605

Image resolution	% Utilization		Image refreshing rate		
	PC1	mainPC	Predicted (fps)	Measured (fps)	% different (meas-pred)
16x16	100.00	52.22	632.91	548.00	15.49
32x32	100.00	66.14	632.91	548.00	15.49
64x64	64.62	100.00	409.00	394.00	3.81
128x128	19.02	100.00	120.41	113.70	5.90
256x256	4.32	100.00	27.32	26.96	1.33

From the table, the % difference between predicted and measured value is quite big. Therefore, image refreshing rate obtained by summing up all corresponding processes time cannot represent the exact refreshing rate. The percentage utilization of PC is computed by summing all processes time of the relevant PC and is divided by the total time per frame. Then, the result is multiplied with 100 to obtain percentage value. This % utilization provides the information of whether the data distribution system can operate in parallel data processing and achieve optimization. The percentage improvements of all cases when applying data distribution system are shown in Table 3.

Table 3. Improvement of image refreshing rate by using data distribution system.

Image resolution	Image refreshing rate (fps)		% Improvement
	Single processing unit	Data distribution system	
16x16	489.30	548.00	12.00
32x32	432.71	548.00	26.64
64x64	253.90	394.00	55.18
128x128	97.65	113.70	16.44
256x256	25.83	26.96	4.37

For the resolution of 64x64, the maximum improvement is obtained, which is 55.18 %. The % utilization of PC1 and mainPC at this resolution are 64.62% and 100% respectively. The data distribution system performs parallel data processing efficiently in this case. For the resolution of 256x256, PC1 has the lowest utilization because it must wait 35.03 ms to ensure that mainPC already finish up the image reconstruction process before capturing the new data. As a result, the data distribution system is unable to improve the performance of this case to a great extent.

4.1.3 Image Reconstruction and MFR Measurement System

This system displays both upstream and downstream images together with mass flow rate result in the ‘Both Images’ page in TomoNet program. Therefore, there are two kinds of refreshing rates, which are image refreshing rate and MFR refreshing rate. This measurement system tries to maintain the image refreshing rate at 28 fps because this value is sufficient for user to obtain flow concentration information and it will not affect the MFR refreshing rate in all types of image resolutions.

By using single processing unit (SPU) in this system, the results obtained are tabulated in Table 4.

The predicted MFR refreshing rate is computed from one over the total time per frame whereas the predicted image refreshing rate is multiplying the predicted MFR refreshing rate with *i* image per frame. 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. In the last two cases, the measured image refreshing rate are quite low because there are not enough time to reconstruct all 28 pairs of images desired in one second. 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.

Table 4. Image and MFR refreshing rates by using SPU system.

Image resolution	x set of data	i img per frame	Time of process					Total time per frame (ms)
			x set data capture	x concentration profiles	i image reconstruction	Velocity profile	MFR result	
no image	100	-	123	1.09	-	12.5	0.41	137.00
	200	-	246	2.18	-	51.6	0.65	300.43
	300	-	369	3.27	-	412.5	0.87	785.64
16x16	100	4	123	1.09	2.876	12.5	0.41	139.88
	200	9	246	2.18	6.471	51.6	0.65	306.90
	300	23	369	3.27	16.537	412.5	0.87	802.18
32x32	100	4	123	1.09	3.756	12.5	0.41	140.76
	200	9	246	2.18	8.451	51.6	0.65	308.88
	300	23	369	3.27	21.597	412.5	0.87	807.24
64x64	100	4	123	1.09	9.356	12.5	0.41	146.36
	200	9	246	2.18	21.051	51.6	0.65	321.48
	300	23	369	3.27	53.797	412.5	0.87	839.44
128x128	100	5	123	1.09	40.995	12.5	0.41	177.99
	200	11	246	2.18	90.189	51.6	0.65	390.62
	300	25	369	3.27	204.975	412.5	0.87	990.62
256x256	100	23	123	1.09	839.477	12.5	0.41	976.48
	200	18	246	2.18	657.000	51.6	0.65	957.43
	300	5	369	3.27	182.495	412.5	0.87	968.14

Image resolution	x set of data	MFR refreshing rate			Image refreshing rate		
		Predicted (fps)	Measured (fps)	% different (meas-pred)	Predicted (fps)	Measured (fps)	% different (meas-pred)
no image	100	7.30	7.27	0.41	-	-	-
	200	3.33	3.31	0.60	-	-	-
	300	1.27	1.25	1.60	-	-	-
16x16	100	7.15	7.11	0.56	28.60	26.50	7.92
	200	3.26	3.22	1.24	29.34	26.91	9.03
	300	1.25	1.21	3.31	28.75	27.01	6.44
32x32	100	7.10	7.05	0.70	28.40	26.50	7.17
	200	3.24	3.19	1.56	29.16	29.30	3.04
	300	1.24	1.20	3.33	28.52	27.61	3.30
64x64	100	6.83	6.82	0.15	27.32	26.58	2.78
	200	3.11	3.10	0.32	27.99	26.10	7.24
	300	1.19	1.16	2.59	27.37	26.00	5.27
128x128	100	5.62	5.55	1.26	28.10	27.54	2.03
	200	2.56	2.50	2.40	28.16	26.08	7.97
	300	1.01	1.00	1.00	25.25	24.03	5.08
256x256	100	1.02	1.01	0.99	23.55	22.90	2.84
	200	1.04	1.04	0.00	18.72	17.50	6.97
	300	1.03	1.03	0.00	5.15	5.01	2.79

The data distribution system (DDS) of this application is constructed by using 3 computers. Each computer has it own function as shown in the flow timing structure in Fig. 6. The predicted and measured refreshing rates are tabulated in Table 5.

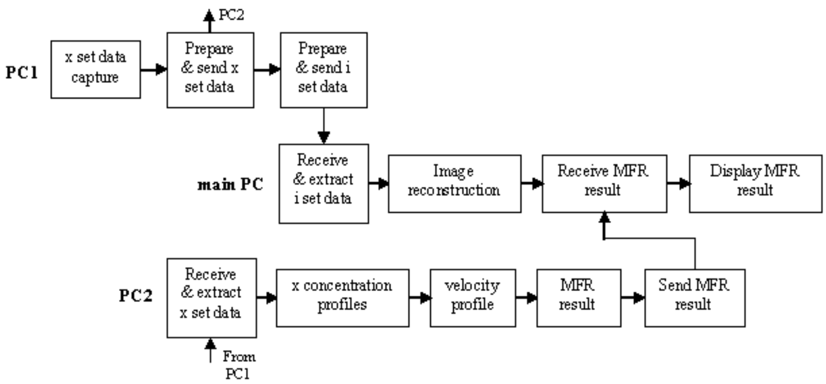


Fig. 6. Flow timing structure of 3 PCs image reconstruction and MFR measurement system.

Table 5. Image and MFR refreshing rates by using 3 PCs measurement system.

Image resolution	x set of data	i image per frame	Time of process (ms)										
			In PC1			In mainPC					In PC2		
			x set data capture	Prepare & send x set data	Prepare & send i set data	Receive & extract i set data	Image reconstruction	waiting	Receive MFR result	Display MFR result	Receive & extract x set data	x concentration profiles	Velocity profile
No image	100	-	123	35	-	-	-	-	0.01	0.26	9.5	1.09	12.5
	200	-	246	70	-	-	-	-	0.01	0.26	19.0	2.18	51.6
	300	-	369	105	-	-	-	-	0.01	0.26	28.5	3.27	512.2
16x16	100	4	123	35	1.40	0.38	2.92	10.70	0.01	0.26	9.5	1.09	12.5
	200	9	246	70	3.15	0.86	6.57	47.00	0.01	0.26	19.0	2.18	51.6
	300	16	369	105	5.60	1.52	11.68	503.14	0.01	0.26	28.5	3.27	512.2
32x32	100	4	123	35	1.40	0.38	3.80	9.82	0.01	0.26	9.5	1.09	12.5
	200	9	246	70	3.15	0.86	8.55	45.02	0.01	0.26	19.0	2.18	51.6
	300	16	369	105	5.60	1.52	15.20	499.62	0.01	0.26	28.5	3.27	512.2
64x64	100	4	123	35	1.40	0.38	8.92	4.70	0.01	0.26	9.5	1.09	12.5
	200	9	246	70	3.15	0.86	20.07	33.50	0.01	0.26	19.0	2.18	51.6
	300	16	369	105	5.60	1.52	35.68	479.14	0.01	0.26	28.5	3.27	512.2
128x128	100	4	123	35	1.40	0.38	30.84	-	0.01	0.26	9.5	1.09	12.5
	200	9	246	70	3.15	0.86	69.39	-	0.01	0.26	19.0	2.18	51.6
	300	16	369	105	5.60	1.52	123.36	391.46	0.01	0.26	28.5	3.27	512.2
256x256	100	4	123	35	1.40	0.38	133.68	-	0.01	0.26	9.5	1.09	12.5
	200	9	246	70	3.15	0.86	300.78	-	0.01	0.26	19.0	2.18	51.6
	300	16	369	105	5.60	1.52	534.72	-	0.01	0.26	28.5	3.27	512.2

Image resolution	x set of data	Time of process (ms)		Total time per frame	% Utilization			MFR refreshing rate			Image refreshing rate		
		In PC2											
		MFR result	Send MFR result		PC1	main PC	PC2	Predicted (fps)	Measured (fps)	% different (meas-pred)	Predicted (fps)	Measured (fps)	% different (meas-pred)
No image	100	0.41	0.22	158.00	100.00	0.17	15.01	6.33	6.29	0.64	-	-	-
	200	0.65	0.22	316.00	100.00	0.09	23.31	3.16	3.14	0.64	-	-	-
	300	0.87	0.22	545.06	86.96	0.05	100.00	1.83	1.77	3.39	-	-	-
16x16	100	0.41	0.22	159.40	100.00	2.24	14.88	6.27	6.25	0.32	25.08	25.02	0.24
	200	0.65	0.22	319.50	100.00	2.41	23.08	3.13	3.12	0.32	28.17	26.74	5.35
	300	0.87	0.22	545.06	87.99	2.47	100.00	1.83	1.76	3.98	29.28	27.54	6.32
32x32	100	0.41	0.22	159.40	100.00	2.79	14.88	6.27	6.25	0.32	25.08	25.02	0.24
	200	0.65	0.22	319.15	100.00	3.03	23.08	3.13	3.10	0.97	28.17	26.75	5.31
	300	0.87	0.22	545.06	87.99	3.12	100.00	1.83	1.76	3.98	29.28	27.10	8.04
64x64	100	0.41	0.22	159.40	100.00	6.00	14.88	6.27	6.25	0.32	25.08	25.00	0.32
	200	0.65	0.22	319.15	100.00	6.64	23.08	3.13	3.12	0.32	28.17	26.81	5.07
	300	0.87	0.22	545.06	87.99	6.87	100.00	1.83	1.74	5.17	29.28	27.45	6.67
128x128	100	0.41	0.22	159.40	100.00	19.76	14.88	6.27	6.26	0.16	25.08	25.02	0.24
	200	0.65	0.22	319.15	100.00	22.10	23.08	3.13	3.12	0.32	28.17	26.75	5.31
	300	0.87	0.22	545.06	87.99	22.96	100.00	1.83	1.78	2.81	29.28	27.33	7.14
256x256	100	0.41	0.22	159.40	100.00	84.27	14.88	6.27	6.25	0.32	25.08	25.00	0.32
	200	0.65	0.22	320.86	99.47	94.09	22.95	3.12	3.12	0.00	28.08	26.74	5.01
	300	0.87	0.22	564.96	84.89	94.96	96.48	1.77	1.65	7.27	28.32	26.54	6.71

As can be seen from the table, 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. The data distribution system can maintain the image refreshing rate to the value of about 26 fps in all cases. For the MFR refreshing rate in the same number of x, the results of all corresponding cases are approximately the same. Besides, the 3 PCs data distribution system can achieve the optimization in the case of 256x256 resolution and x = 300 because all of the PCs have high utilization, i.e. 84.89%, 94.96% and 96.48% for PC1, mainPC and PC2 individually. The following table shows the comparison of refreshing rate between single processing unit system and data distribution system.

From the observation, Table 6 it is found that the maximum improvement of MFR refreshing rate occurs at the resolution of 256x256 and x = 100, which is 518.81%. In this measurement system, the improvement of image refreshing rate is not important because the purpose of this system is maintaining the image refreshing rate to the value of about 28 fps. However, it can be seen that the maximum improvement of image refreshing rate happens in the last case, which is 429.74%.

Table 6. Improvement of image and MFR refreshing rates by using 3 PCs DDS.

Image resolution	x set of data	MFR refreshing rate (measured)			Image refreshing rate (measured)		
		SPU (fps)	DDS (fps)	% improvement	SPU (fps)	DDS (fps)	% improvement
No image	100	7.27	6.29	-13.48	-	-	-
	200	3.31	3.14	-5.14	-	-	-
	300	1.25	1.77	41.60	-	-	-
16x16	100	7.11	6.25	-12.10	26.50	25.02	-5.58
	200	3.22	3.12	-3.11	26.91	26.74	-0.63
	300	1.21	1.76	45.45	27.01	27.54	1.96
32x32	100	7.05	6.25	-11.35	26.50	25.02	-5.58
	200	3.19	3.10	-2.82	28.30	26.75	-5.48
	300	1.20	1.76	46.67	27.61	27.10	-1.85
64x64	100	6.82	6.25	-8.36	26.58	25.00	-5.94
	200	3.10	3.12	0.65	26.10	26.81	2.72
	300	1.16	1.74	50.00	26.00	27.45	5.58
128x128	100	5.55	6.26	12.79	27.54	25.02	-9.15
	200	2.50	3.12	24.80	26.08	26.75	2.57
	300	1.00	1.78	78.00	24.03	27.33	13.73
256x256	100	1.01	6.25	518.81	22.90	25.00	9.17
	200	1.04	3.12	200.00	17.50	26.74	52.80
	300	1.03	1.77	71.84	5.01	26.54	429.74

5. Discussions

From the two different real-time measurement systems developed in this research, it can be observed that data distribution system is able to improve the existing result of 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 number of x set data to be cross-correlated. Otherwise, data distribution system will impair the performance of existing system.

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 percentage utilization of computers used in the data distribution system is also a crucial element. If the percentage 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 percentage utilization near to 100%.

In the image reconstruction system, the % improvement by using data distribution system is illustrated in Fig. 7.

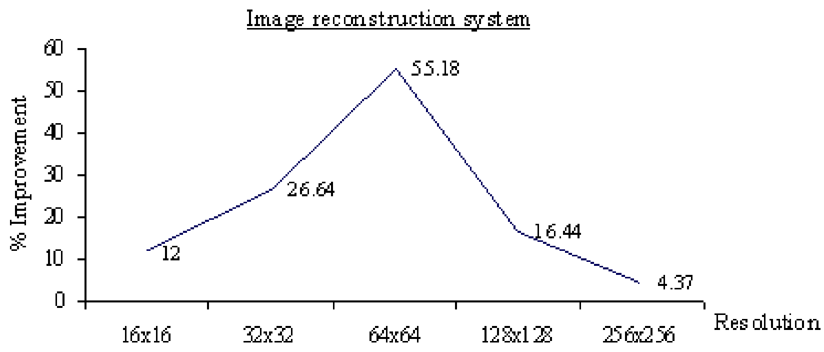


Fig. 7. The graph of %improvement versus resolution in image reconstruction system.

The graph above shows that the % improvement is in increment at the first three resolutions. Then, the % improvement decreases dramatically. The peak of % improvement occurs at the resolution of 64x64, which is 55.18%.

In the investigation of image reconstruction and mass flow rate measurement system, the % improvement obtained by using data distribution system is shown in graph of Fig. 8.

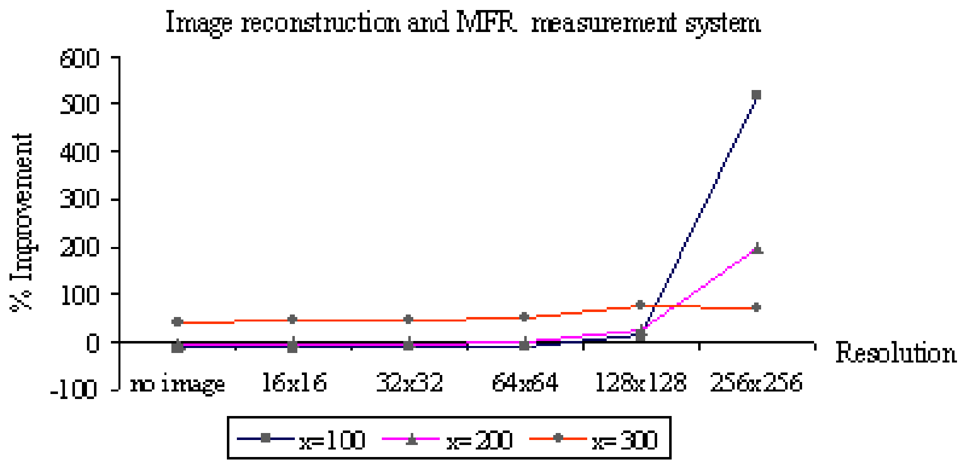


Fig. 8. The graph of MFR refreshing rate improvement versus resolution in image reconstruction and MFR measurement system.

For x = 100 and x = 200, the % improvement starts 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.

6. Conclusions

In conclusion, all kinds of data distribution system have their own maximum improvement regarding to the corresponding setting. As long as the measurement system of data distribution system operates in this condition, the system's performance obtained will be definitely better than by using single processing unit in the measurement system.

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Guide for Contributors

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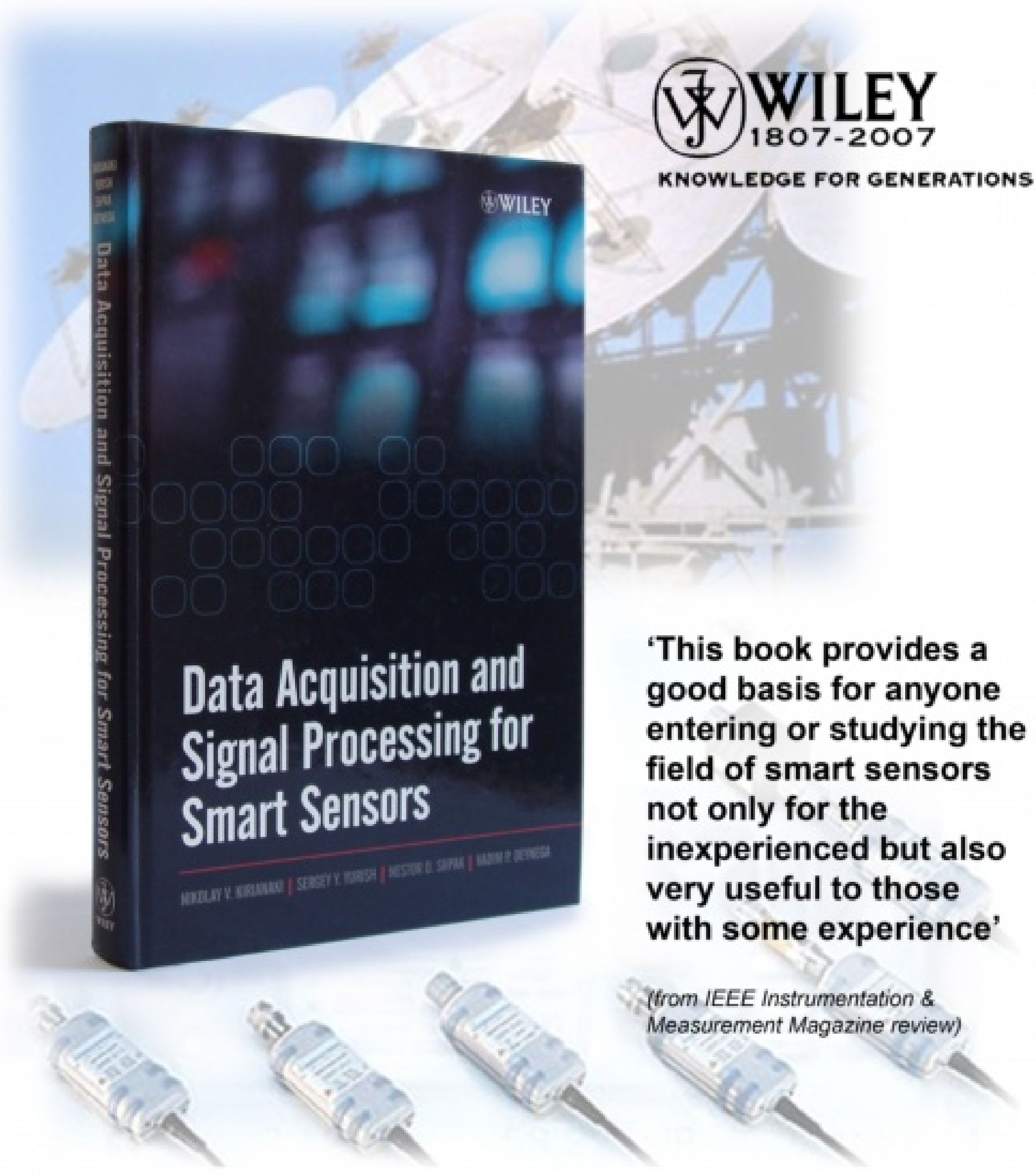
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