Optical Tomography using Multiple Fan-Beam Projection Technique

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ABSTRACT

This paper presents the timing advantage of implementing multiple fan beam projection technique using optical fibre sensors for a tomography system. To prepare the optical fibre sensors to be used for this multiple fan beam projection, a collimator is not needed but optical fibre lens termination is crucial. In this research, the fibre optic lens for transmitters is modelled by experimental methods to transmit light at an emission angle of 30 degree. Due to its small emission angle, multi projection technique can be implemented without the lights overlapping. Multiple fan beam projection technique here is defined as allowing more than one emitter to project light at the same time using the switch mode fan beam method. This method used is able to increase the optical sensor's ability in flow visualization. For the 32 pairs of sensors used, the 2 projection technique and 4 projection technique are being investigated. 16 sets of projections will complete one frame of light emission for the 2 projection technique while 8 sets of projection will complete one frame of light emission for the 4 projection technique. Compared to the conventional single light projection used in switch-mode fan beam method, multiple light projections can achieve a higher data acquisition rate, thus minimizing data lost and producing a more accurate real-time tomographic image.

Keywords Optical fibre sensors, multiple fan beam projection technique, 2 projection technique, 4 projection technique, real time.

1. Introduction

Process tomography is an emerging imaging technique which encapsulates a wide variety of sensor types, design principles and performance goals. As such, the parameters for the tomography field investigated in this paper are to be identified. Sensors in the measurement of a tomography system prove to be the most important part in acquiring the physical signal. Based on the fact that optical fibre sensors are smaller in physical size and able to increase the resolution of the hardware system, it is thus chosen as a tool to implement the multiple fan beam projection technique for a 80mm pipeline system. There are a total of 64 optical fibre sensors installed to the sensor's fixture which comprised of 32 transmitters and 32 receivers.

2. Preparation of sensors

In using optical fibre sensors for tomographic imaging, the basic optical transmitter converts electrical input signals into modulated light for transmission over an optical fibre. Also, the light beam from the transmitter is being received by the receiver via the fibre optic. The basic optical fibre sensors configuration is illustrated in Figure 1.

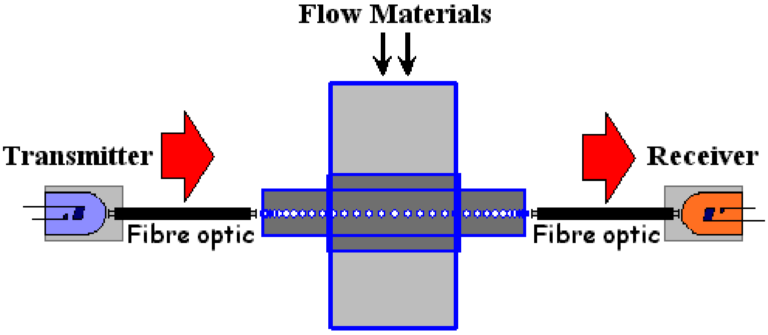


Figure 1: Basic optical fibre sensors configuration

From Figure 1, the arrow explains the direction of light beam whereby the emitter will transmit light into the while the receiver will receive light. The information received by the receivers will be manipulated in the signal conditioning circuit (i.e. conversion of current to voltage and amplification) before being transferred to the computer for image reconstruction. This section will discuss the preparation of the fibre optics to perform as optical sensors.

The choice of using single core polymer cable fibre optic (with core diameter at 1.00mm and overall diameter at 2.25mm) instead of the fibres made of glass for this research is because the former is more affordable, easier to install [1] and since the core is made of plastic instead of glass, terminating the cable will be easier. Before the fiber optic can be used, it must be properly lensed. This is because the termination of the ends of fibre optics will affect the acceptance and emission angles of the light energy transmitted by the fibre [2]. A simple but effective approach has been taken to terminate the optical fibres. After cutting the fibre optics according to desired lengths using a very sharp fibre optic cutter, the cladding/sheath of 4mm at each end of the cable is being cut (refer to Figure 2). Cutting off the sheath must be done with great care in order not to hurt the inner core of the fibre optic to prevent transmission loss.

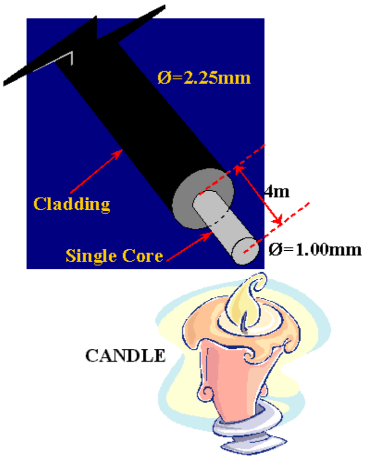


Figure 2: Optical fibre end termination.

After the sheath is being cut, the fibre optics can be lensed. The fibre optic has a numerical aperture of 0.47 and acceptance angle of 28^0 as stated in the data sheet. The numerical aperture determines the acceptance cone of the fibre [3]. Equation 1 gives us the formula to calculate the numerical aperture and Figure 3 shows the acceptance angle of an optical fibre. The total receiving angle for the fibre optic is two times the acceptance angle and in this case, it is 56^0.

$$NA = \sin \theta_A \qquad \dots (1)$$

Whereby NA is the numerical aperture of the fibre optic and θ_A is the acceptance angle of fibre optic.

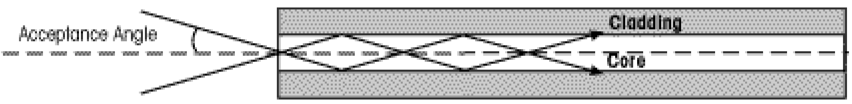


Figure 3: The acceptance angle for optical fibre.

For the fibre optic to be used as transmitter, the end of the exposed core is placed close to a naked flame for a few seconds until the end softens and forms a curved surface due to surface tension as shown previously in Figure 2. Excessive heat will melt the fibre completely and this should be avoided. This curvature develops a 'lens' in the fibre, which is an improvement over an unlensed fibre, because it provides improved light transfer [4]. There are other approaches to lensing the fibre optic; however, this simple and inexpensive method is sufficient for the application in this research.

Unlike in the application of optical fibre sensors in parallel beam projection, the emission beam should not concentrate in a straight line. Instead, the emitted fan beam should have a transmission angle. Preliminary testings show that the maximum achievable emission angle for the fibre optic transmitter is about 30°, after the fibre optic is being lensed. There are 32 fibre optic transmitters that are being used in this research; thus in order to make sure that the emission angle is approximately the same, each of the fibre optic emission angles is being tested experimentally as illustrated in Figure 4.

Using a white sheet and geometry drawing tools, the circle which represents the 80mm diameter pipeline is being drawn. An angle of 30 degrees is measured using the protractor and drawn. By placing the fibre optic near to the paper, the infrared emitter is supplied with current to emit light. The fibre optic for transmitter will be lensed until the light beam from the fibre optic matches the trace of 'light' on the white sheet. This means that the emission angle has reach 30°. All the 32 fibre optics for transmitters' angles is determined experimentally this way.

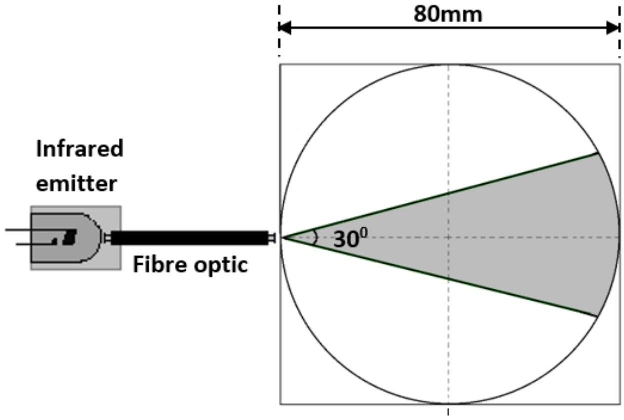
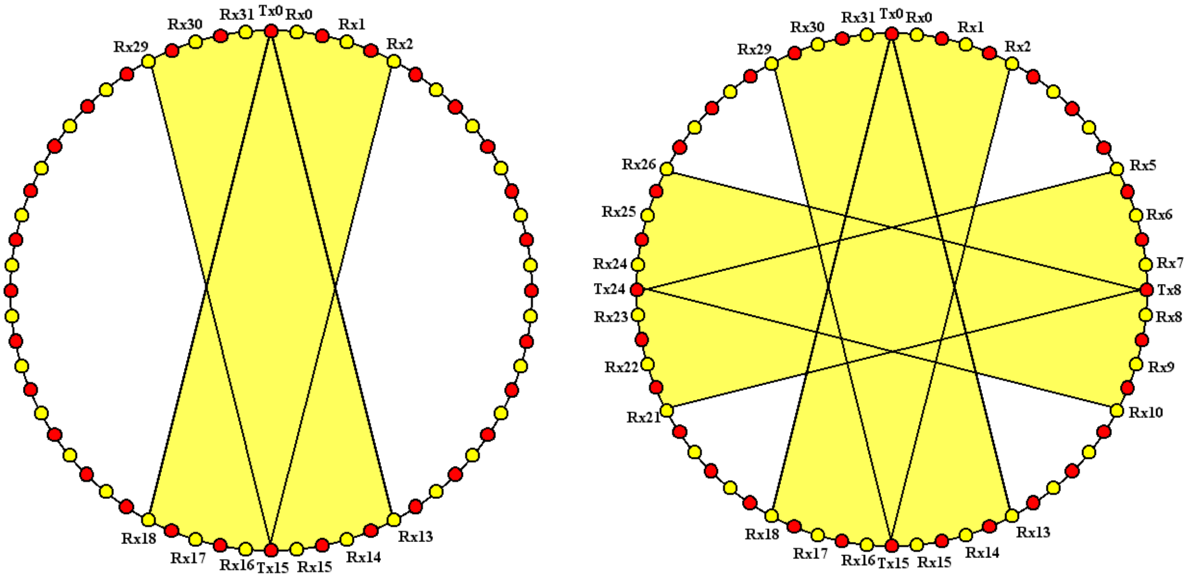


Figure 4: Determining emission angle.

3. Multiple Fan Beam Projection Geometry

Implementation of the multiple projection technique using switch-mode fan beam method yields two projection geometries which are the 2-projection geometry and the 4-projection geometry. When two or four transmitters project light at the same time, the total time to complete one frame of data acquisition will be shorter, thus it is believed that both these techniques are able to achieve better timing performances in data acquisition process compared with the conventional single light projection. The projection geometry of both the techniques is shown in Figure 5.



(a) **(b)**

Figure 5: Multiple projection geometry a) 2-Projection b) 4-Projection

Considering that the 32 transmitters and 32 receivers are arranged alternately in clockwise starting from Tx0, Rx0, Tx1, Rx1 until Tx31 and Rx31, the transmitters emit light according to this arrangement sequence. At a transmission angle of 30 degrees, each projection provides six light beams (6 views) which will be received by the corresponding receivers as tabulated in Table 1.

Table 1: Transmitters and corresponding receivers' configuration.

Transmitter	Receiver						Transmitter	Receiver					
Tx0	Rx 13	Rx 14	Rx 15	Rx 16	Rx 17	Rx 18	Tx16	Rx 29	Rx 30	Rx 31	Rx 0	Rx 1	Rx 2
Tx1	Rx 14	Rx 15	Rx 16	Rx 17	Rx 18	Rx 19	Tx17	Rx 30	Rx 31	Rx 0	Rx 1	Rx 2	Rx 3
Tx2	Rx 15	Rx 16	Rx 17	Rx 18	Rx 19	Rx 20	Tx18	Rx 31	Rx 0	Rx 1	Rx 2	Rx 3	Rx 4
Tx3	Rx 16	Rx 17	Rx 18	Rx 19	Rx 20	Rx 21	Tx19	Rx 0	Rx 1	Rx 2	Rx 3	Rx 4	Rx 5
Tx4	Rx 17	Rx 18	Rx 19	Rx 20	Rx 21	Rx 22	Tx20	Rx 1	Rx 2	Rx 3	Rx 4	Rx 5	Rx 6
Tx5	Rx 18	Rx 19	Rx 20	Rx 21	Rx 22	Rx 23	Tx21	Rx 2	Rx 3	Rx 4	Rx 5	Rx 6	Rx 7
Tx6	Rx 19	Rx 20	Rx 21	Rx 22	Rx 23	Rx 24	Tx22	Rx 3	Rx 4	Rx 5	Rx 6	Rx 7	Rx 8
Tx7	Rx 20	Rx 21	Rx 22	Rx 23	Rx 24	Rx 25	Tx23	Rx 4	Rx 5	Rx 6	Rx 7	Rx 8	Rx 9
Tx8	Rx 21	Rx 22	Rx 23	Rx 24	Rx 25	Rx 26	Tx24	Rx 5	Rx 6	Rx 7	Rx 8	Rx 9	Rx 10
Tx9	Rx 22	Rx 23	Rx 24	Rx 25	Rx 26	Rx 27	Tx25	Rx 6	Rx 7	Rx 8	Rx 9	Rx 10	Rx 11
Tx10	Rx 23	Rx 24	Rx 25	Rx 26	Rx 27	Rx 28	Tx26	Rx 7	Rx 8	Rx 9	Rx 10	Rx 11	Rx 12
Tx11	Rx 24	Rx 25	Rx 26	Rx 27	Rx 28	Rx 29	Tx27	Rx 8	Rx 9	Rx 10	Rx 11	Rx 12	Rx 13
Tx12	Rx 25	Rx 26	Rx 27	Rx 28	Rx 29	Rx 30	Tx28	Rx 9	Rx 10	Rx 11	Rx 12	Rx 13	Rx 14
Tx13	Rx 26	Rx 27	Rx 28	Rx 29	Rx 30	Rx 31	Tx29	Rx 10	Rx 11	Rx 12	Rx 13	Rx 14	Rx 15
Tx14	Rx 27	Rx 28	Rx 29	Rx 30	Rx 31	Rx 0	Tx30	Rx 11	Rx 12	Rx 13	Rx 14	Rx 15	Rx 16
Tx15	Rx 28	Rx 29	Rx 30	Rx 31	Rx 0	Rx 1	Tx31	Rx 12	Rx 13	Rx 14	Rx 15	Rx 16	Rx 17

For the 2-projection technique, sixteen sets of projections will complete one frame of light emission whereby Tx_n and Tx_{16+n} (with n as the respective number projection ranging from 0 to 15) will transmit light at the same time. As for the 4-projection technique, eight sets of projections will complete one frame of light emission with Tx_n, Tx_{8+n}, Tx_{16+n} and Tx_{24+n} (taking n as the respective number projection ranging from 0 to 7) transmitting light at the same time.

4. Data Acquisition Rate (DAR)

In real-time data acquisition, the data acquisition rate plays a major role in determining how 'real' the online measurement is. In the condition whereby the sampling rate or experimental span is too low, information about the detailed fluctuations of the continuous waveform signal will be lost [5]. For different people, the term 'real-time' is very abstract; arguments arise about the duration of time that can be accepted as online measurement. Thus, for comparison purposes, the result of this paper is compared with previous research done by Chan (2002). For a total number of 16 pairs of optical sensors employed by Chan (2002) [6], the data acquisition rate obtained is 300 fps. In this research, the number of sensors is doubled to 32 pairs, thus the data acquisition rate will be theoretically lower. The aim of this paper is to achieve a higher data acquisition rate of at least 600fps. Therefore, the multiple projection technique is implemented in this research to attain a higher data acquisition rate for an increased number of sensors.

Generally, the Data Acquisition Rate or DAR can be defined as the measurement of how fast the acquired signals are transferred from the hardware to the Data Acquisition System in one frame. Basically, it can be explained in a simple manner according to Equation 2.

$$DAR = \frac{1}{Total\,Conversion\,Time} \quad \ldots (2)$$

whereby *DAR* is the data acquisition rate in unit frame per second (fps) and *Total Conversion Time* is the total time needed to convert all the 32 receivers' signals in one frame (for either in the 2-projection or 4-projection mode).

For data acquisition process, the Keithley DAS 1802HC is being used. The maximum sampling rate for the data acquisition system (DAS) card is 333ksamples/second, whereby the sampling time for a single sample is 3µs. The ideal conversion time is usually not achievable in real hardware; therefore, as a safe approach to make sure that all the conversions are done in the time duration given, the conversion time for the 32 sensors is set to be longer than the ideal conversion time.

The rising edge of the digital control signal, TGOUT is generated from DAS when user sends a signal to DAS to start conversion. It remains at 5 volt until one frame of conversion process finishes. Thus, if we probe the TGOUT signal, we can measure the total conversion time for one frame of data. For a system which runs at 5 kHz in this research, the TGOUT signals probed for both the 2-projection and 4-projection modes are shown in Figure 6.

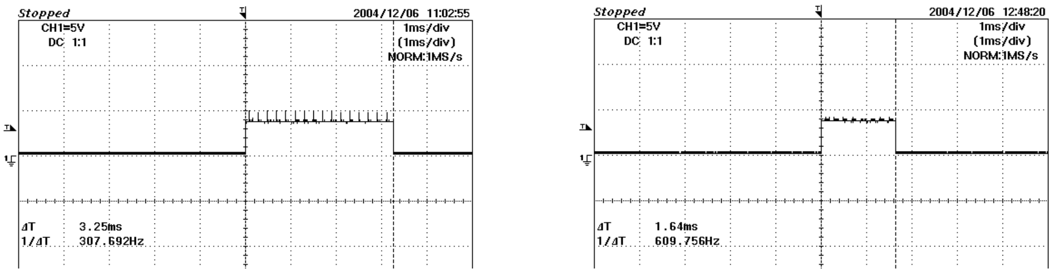


Figure 6: Total conversion time for one frame data a) 2-projection b) 4-projection

Based on Equation 2, the DAR obtained for both the projection modes are shown in Table 2.

Projection Mode	Total Conversion time	DAR
2-projection	3.25 ms	307.69 fps
4-projection	1.64 ms	609.76 fps

Table 6.2: DAR for different projection modes.

It is proven here that the 4-projection mode has the ability to achieve higher DAR compared to the 2-projection mode. In the previous optical fan beam tomography research by Chan (2002)[6], he used a total of 16 receivers with single projection each for 16 transmitters. He has managed to achieve a DAR of 300 fps. Theoretically, by using the conventional single projection technique with an increased number of sensors, the total time to convert one frame of data would be longer. It is known that a high DAR when acquiring data is essential in optical tomography system to prevent data loss.

Thus, by comparing the number of sensors and DAR obtained by Chan (2002)[6] with the results achieved in this research, it has been verified that the multiple projection technique has a capability to increase the resolution of the hardware system (a higher number of sensors installed) and at the same time increasing the DAR (shorter time needed for data conversion in one frame). The graph shown in Figure 7 represents the improvement for the DAR achieved by multiple projection technique in this research when compared to the single projection result achieved by Chan (2002)[6].

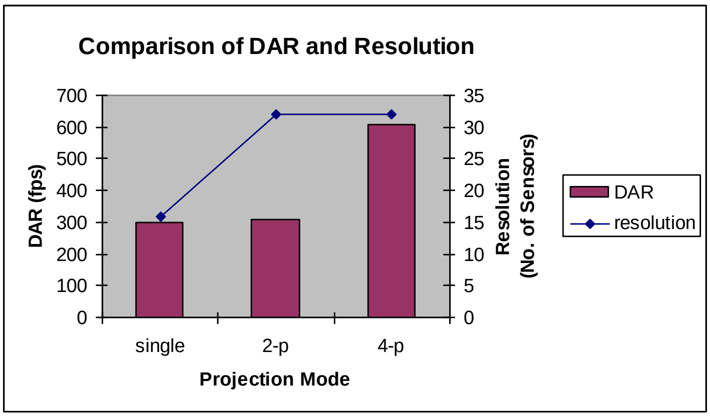


Figure 7: Comparison of DAR and resolution.

In the graph, the resolution represents the number of sensors installed in the hardware system. The 2-projection technique spots an increase of 2.56% while the 4-projection technique shows an amazing increase of about 103.25% in DAR compared to the previous research by Chan (2002)[6].

5. Conclusions

Implementation of the multiple fan beam projection technique using switch-mode fan beam method has proved that the data acquisition rate (DAR) of the optical fibre sensors system can be improved significantly up to 609.76 fps by using the 4-projection technique. The achievable high data acquisition rate enables the optical fibre sensors system to perform real-time flow visualization with minimal data loss. The implementation of optical fibre sensors gives an added advantage by allowing the hardware system to perform in high resolutions. In addition, the preparations of the fibre optics to be used as transmitters and receivers are done in a simple and low-cost manner.

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