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INVESTIGATING MULTIPLE FAN BEAM PROJECTION TECHNIQUE USING OPTICAL FIBRE SENSOR IN PROCESS TOMOGRAPHY

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Abstract. This paper investigates the acquisition rate for a multi-projection technique using optical fibre sensors for a fan beam optical tomography system. The multi-projection technique allows more than one emitter to project light at the same time. For the 32 pairs of sensors used, the 2-projection technique is being investigated whereby 16 sets of projections will complete one frame of light emission. Compared to the conventional single light projection technique used in switch-mode fan beam, multiple light projections technique has shown to be able to achieve a higher data acquisition rate.

Keywords: Optical fibre sensor, fan beam optical tomography, multi-projection technique, switch-mode fan beam method

Abstrak. Secara umumnya, objektif projek ini adalah untuk mengimplimentasi teknik sinaran berbilang "*fan beam*" menggunakan penderia gentian optik dengan tujuan meningkatkan kadar perolehan data. Teknik sinaran berbilang "*fan beam*" dalam kes ini boleh didefinisikan sebagai membenarkan lebih daripada satu pemancar untuk memancarkan cahaya dalam suatu masa yang sama dengan menggunakan kaedah "*switch-mode fan beam*."

Kata kunci: Penderia gentian optik, tomografi optik *fan-beam*, teknik berbilang pemancar, kaedah *switch-mode fan beam*

1.0 INTRODUCTION

Process tomography is a developing measurement technology. Over the last decade, the concept of tomographic imaging was not restricted to medical field only; it has been successfully developed into a reliable tool for imaging numerous industrial applications. Sensors in the measurement system prove to be the most important part in acquiring the physical signal. The physical signal is then being converted, amplified and fed into the computer to obtain the internal behaviours of the investigated vessel.

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A conveyor with fast moving flow and rapid changing flow regime require a sensor with very fast response and also a high data acquisition rate in order to prevent data losses. The optical tomography sensors have proven to have the advantages such as fast response, high resolution and low maintenance compared to the electrical capacitance tomography [7].

2.0 OPTICAL FIBRE FOR TOMOGRAPHY IMAGING

Mass production of optical fibre has reduced the cost of the fibres significantly and more importantly the revolution brought simultaneous improvements and cost reduction in optoelectronic components [8]. In the area of tomographic imaging, an initial investigation into using fibre optic as measurement sensors in pneumatic conveying first started in the Sheffield Hallam University, UK [1].

In using optical fibre for tomography 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 [9]. This configuration is being illustrated in Figure 1. With regard to its small physical size, it is believed that using fibre optic will allow a higher number of optical sensors to be installed, thus achieving high-resolution measurement in optical tomography. It is also found that the optical fibre sensors provide wide bandwidth which enables measurements to be performed on high speed flowing particles [2].

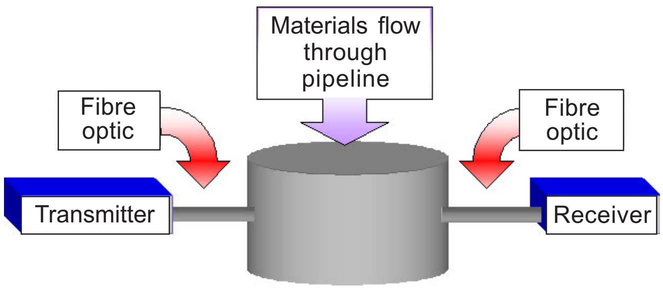


Figure 1 Fibre optic configuration

3.0 SWITCH-MODE FAN BEAM METHOD

Parallel projection and fan beam projection are two different types of sensor arrangement methods. For sensor arrangement method using parallel projection method, each transmitter and receiver only corresponds to each other. For the fan beam projection method, there may be more than one receiver corresponding to a single or multiple light sources.

In the switch-mode fan beam method, a multiplexing source is used and all the receivers produce the signals corresponding to each multiplexed source. Figure 2

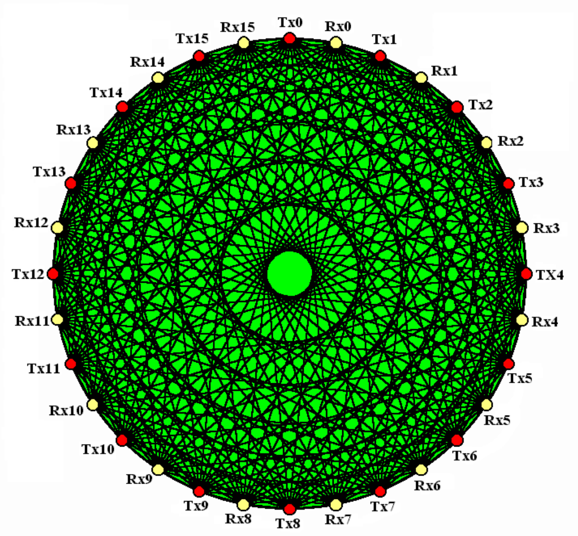


Figure 2 Sensor configuration in switch-mode fan beam projection method

shows the sensors' configuration of fan beam projection method whereby the transmitters and receivers are arranged alternately.

By assuming that the transmitter is an LED which has a wide transmission angle of 140°, the LED or Tx_n will be turned on subsequently whereby the subscript n here represents different LEDs [3,4]. Generally, the main objective of this project is to implement the multiple fan beam projection technique using optical fibre sensors with the aim to achieve a high data acquisition rate.

4.0 HARDWARE CONSTRUCTION

A typical optical tomography system consists of an array of sensors, signal control and conditioning circuit and also a display unit, namely the computer. In this research, instead of mounting the transmitters and receivers straight to the pipeline as carried out by Chan [3], optical fibres were used. A total of 64 fibre optics were used, whereby 32 fibre optics were connected from the sensor's fixture (at the circumference of the flow rig) to the emitters and the other 32 fibre optics were connected to the receivers. The topology of the hardware construction is shown in Figure 3.

By referring to Figure 3, the micro controller is used to control the duration of light projection, sample and hold digital input and data acquisition system (DAS) synchronization signals. Through the fibre optics, photodiodes detect the physical signals (light beams) from the transmitters. In the signal conditioning circuit, the physical signals are being converted into voltage readings and then amplified. The analogue signals go through the sample and hold circuit before being transferred into DAS. DAS then converts the analogue signals into digital signals. These digital signals are being sent to the PC for image reconstruction.

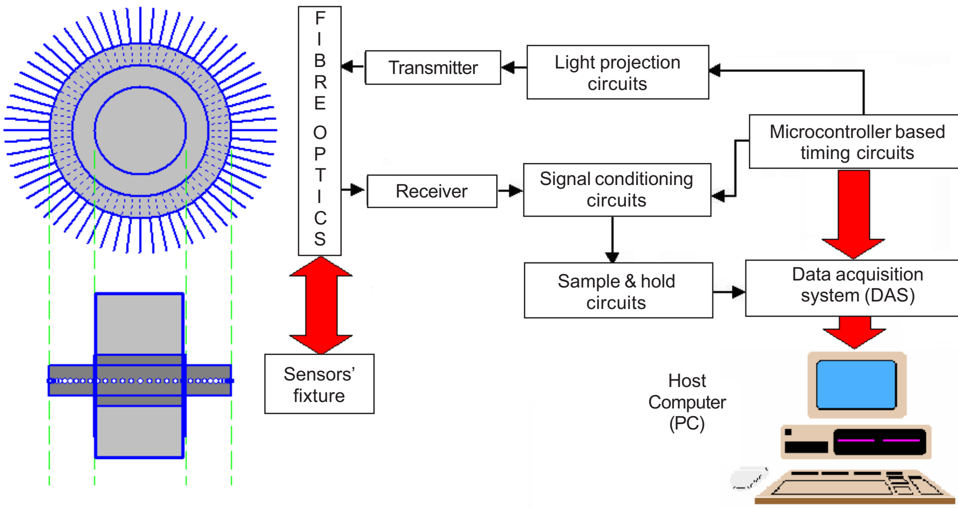
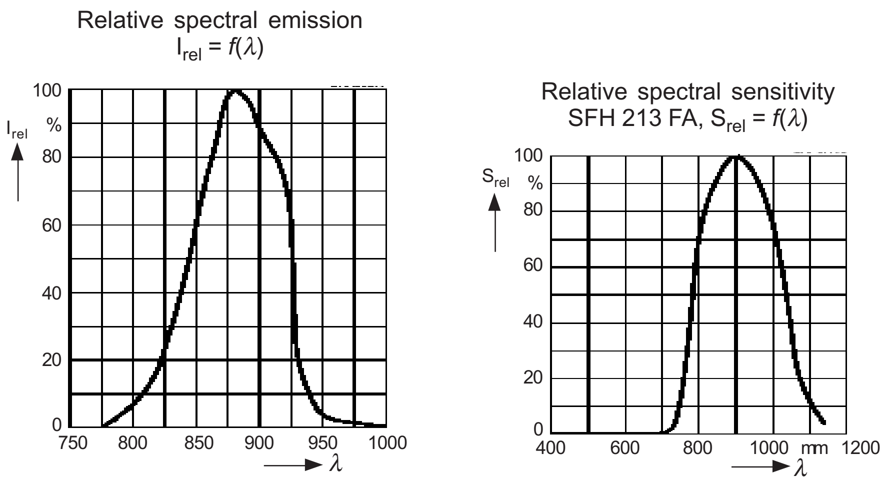


Figure 3 Topology of the hardware construction

5.0 PREPARATION OF SENSORS

There are several steps in preparing the sensors for tomography imaging. In this research, the transmitter used was the SFH484-2 GaAlA infrared emitter and the SFH213-FA silicon pin photodiode was being selected as the receiver. Both the infrared (IR) transmitter and photodiode have a relative spectral sensitivity and emission range of 750 nm to 1100 nm.



(a) Emission (b) Sensitivity

Figure 4 Relative spectral range

The wavelength at peak emission for both transmitter (Figure 4(a)) and receiver (Figure 4(b)) is at ±880 nm, making them compatible. At a peak wavelength of ±880 nm, the performance of the photodiode would not be easily affected by visible light (wavelength of 380 nm to 700 nm). This will minimize noise generation in the circuits when acquiring data from the sensors.

As stated earlier in this paper, the optical fibres are used together with the selected transmitters and receivers. The choice of using single core polymer cable fibre optic (with core diameter at 1.00 mm and overall diameter at 2.25 mm) instead of the fibres made of glass is because the former is more affordable, easier to install 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 [5].

Due to time limitation and financial constraints, 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 (4 mm) at each end of the cable is being cut (refer to Figure 5). Cutting off the sheath must be done with great care in order not to hurt the inner core of the fibre optic to prevent light transmission loss.

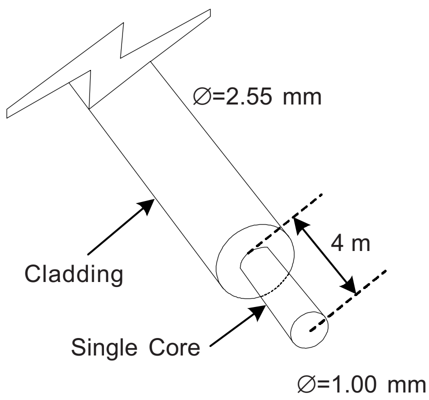


Figure 5 Optical fibre end termination

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 56° as stated in the data sheet. The numerical aperture determines the acceptance cone of the fibre [6].

Equation (1) shows the formula to calculate the numerical aperture and Figure 6 shows the acceptance angle of an optical fibre. The total receiving angle for the fibre optic is twice the acceptance angle and in this case, it is 56°.

$$NA = \sin\theta_A \tag{1}$$

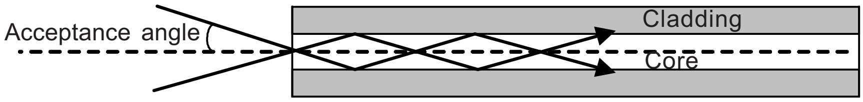


Figure 6 The acceptance angle for an optical fibre

Whereby:

NA = numerical aperture of the fibre optic.

θ_A = acceptance angle of the fibre optic.

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 testing shows 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 angles are approximately the same, each of the fibre optic emission angle is being tested experimentally as illustrated in Figure 7. The pipe diameter used is 80 mm.

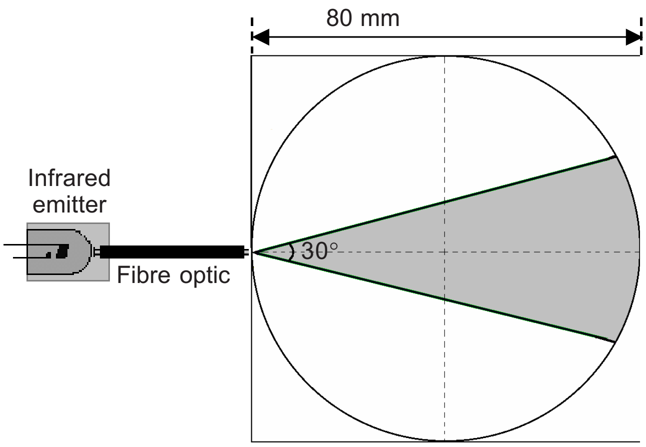


Figure 7 Determination of the emission angle

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. 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 [1]. There are other approaches to lensing the fibre optic; however, this simple and inexpensive method is sufficient for this research.

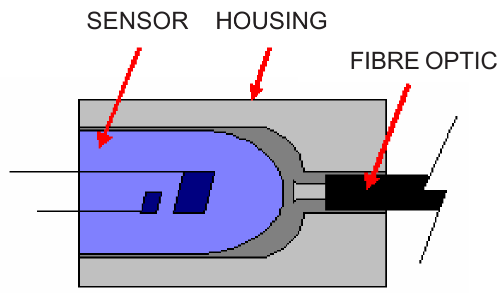


Figure 8 Coupling between sensor and fibre optic

Furthermore, to avoid transmission loss when the fibre optics is coupled with the IR emitters and photodiodes, a custom made housing is being used. The housing is made of PVC and designed as such to hold both the IR emitters/photodiodes and fibre optics to make sure that the connection area is small and the lights can be directed straight, either from the emitters to the fibre optics or light from the fibre optics to the receivers. Figure 8 shows the coupling between the sensor and fibre optic.

6.0 MULTI-PROJECTION TECHNIQUE

A new technique in implementing the switch-mode fan beam method is being investigated in this paper. The technique mentioned is the 2-projection technique. Preliminary experiments show that the maximum achievable emission angle for the fibre optic transmitter is about 30°, after the fibre optic was lensed. Thirtytwo fibre optic transmitters were used in this research. Thus in order to make sure that the emission angles are approximately the same, each fibre optic emission angle was tested experimentally. The experimental method is illustrated in Figure 9.

The fibre optic for transmitter will be lensed until both the Rx receives signals. This means that the emission angle has reach 30°. All the 32 fibre optics for transmitters' angles will be determined experimentally this way.

Due to the limitation of the fibre optic's emitting angle, it is indeed an advantage to implement multi-projection to the light projecting system without worrying about the overlapping of received photodiode signals. For the 32 transmitter model, Tx_n and Tx_{16+n} will project light at the same time, for example, Tx_0 and Tx_{16}, Tx_1 and Tx_{17} etc. will project light at the same time. Sixteen sets of projection will complete one frame of light emission. This will also minimize the total time for one frame of data to be sent to the computer, thus obtaining a higher data acquisition rate.

7.0 DATA ACQUISITION RATE (DAR)

For the data acquisition process, the Keithley DAS 1802 HC was used. The maximum sampling rate for the DAS card is 333 ksamples/second, whereby the sampling time

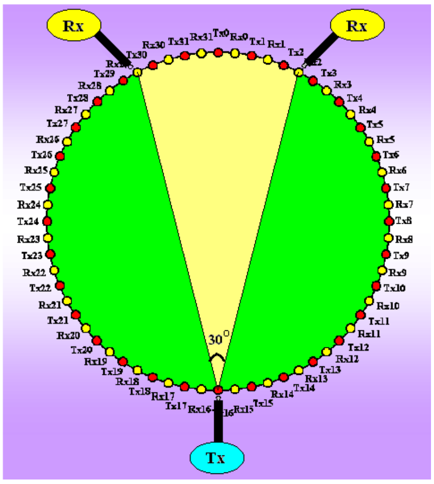


Figure 9 Determining emission angle

for a single sample is 3 μs. Thirtytwo samples have to be converted into voltage readings for each projection, in which each sample took 3 μs to convert. Hence, a total of 96 μs is needed to complete the conversion. 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 32 sensors is set at 200 μs. Having 16 sets of projection altogether to complete one frame of data, the total time needed is 3.2 ms. The data acquisition rate with the unit frame per second (fps) is achieved according to the Equation (2):

$$DAR\,(fps) = \frac{1}{total \cdot conversion \cdot time} \tag{2}$$

The advantage of implementing multi-projection technique compared to the traditional single-projection technique can be emphasized in terms of calculating the DAR. A higher DAR is essential when acquiring data in optical tomography to prevent signal loss. The comparison between the DAR for both the mentioned projection techniques is shown in Table 1.

Table 1 DAR comparison between single-projection and multi-projection technique

	Single-projection	**Multi-projection**
Conversion time for 32 sensors	200 μs	200 μs
Number of projections in one frame	32 individual projections	16 sets of projections
Total time for one frame	6.4 ms	3.2 ms
DAR	156 fps	313 fps

From Table 1, it can be seen clearly that the DAR for the multi-projection technique shortens the total conversion time for one frame of data compared to the single-projection technique, thus increasing the DAR to about double the DAR value for single-projection technique.

8.0 CONCLUSION

The multi-projection technique using optical fibre sensors has been investigated in this paper. By implementing this technique together with the switch-mode fan beam method, it is concluded that a higher data acquisition rate can be achieved in the data acquisition process in optical tomography. The preparations of the fibre optics to be used as transmitters and receivers were done in a simple and low-cost manner. Steps to reduce signal loss were also taken into consideration to produce better and more accurate flow visualization.

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