OPTICAL TOMOGRAPHY: A REVIEW ON SENSOR ARRAY, PROJECTION ARRANGEMENT AND IMAGE RECONSTRUCTION ALGORITHM

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ABSTRACT. This paper reviews previous research on sensor arrays, projection arrangements and image reconstruction algorithms of optical tomography for industrial processes. These include the review of sensor selection and projection arrangement technique to optimize system performance. Issues on types of algorithm for image reconstruction purposes, which is one of the factors to increase the resolution of the image, will also be elaborated. This review could provide a preliminary decision overview for students or researchers before initiating a research related to optical tomography.

Keywords: Optical tomography, Projection, Sensor, Image reconstruction, Industrial process

1. Introduction. Tomography flow measurement is well known in the industrial process. Tomography is vital to investigate activities of internal structures of a vessel without the need to invade it. There are several important parameters that can be investigated by using tomography method such as mass flow rate, velocity profile and concentration profile. These parameters are crucial for industrial process in obtaining good quality product with high safety features. Thus, this paper highlights the initial work of this system, which is essential before beginning any operation. Several methods of tomography are being used in industrial application and one of them is optical tomography introduced by Abdul Rahim et al. [1]. X-ray tomography is the earliest technique applied in medical field before it is widely adapted for industrial application. Both methods have the same concept which consists of a group of sensors placed around the vessel or pipelines to view the distribution of the component within the sensing zone. The main difference between medical and industrial application is the state of the subject that needs to be measured. In medical, the measured subject is static while, in process industry, it involves
a dynamic process. Therefore, there are various factors that need to be considered in order to optimize performance of the system. Figure 1 shows the overall process of an optical tomography system.

Figure 1. Optical tomography system

This paper deliberates three main aspects that affect the measurement output of the system. There are selection of appropriate sensor, projection arrangement and image reconstruction algorithm. Concise introduction which includes related works of optical tomography in general will be discussed. Then, we will look into the sensor choice and projection technique which is followed by image reconstruction algorithms. Finally, the discussion will be finalized at the last part of the paper.

2. Recent Research in Optical Tomography. There are many research works and research groups that had established their own research niche in optical tomography. Sheffield Hallam University, for example is among the active groups involved in optical tomography. Their research focuses on a variety of experiments which utilizes optical sensors [1-7]. The ongoing research in Universiti Teknologi Malaysia (UTM) focuses on solid gas where several of them used parallel and fan beam projection. The most frequent sensors used in their research are infrared LED, laser and fiber optic [1-3,6-21]. Other related groups are from Zheijiang University, China, which focused on near infrared laser and Terahertz PT (Process Tomography) [22,23]. The group from Guangdong University of Technology, China studied the fan beam optical sensor and its application in mass flow rate measurement of pneumatically conveyed solids [24,25]. In Beijing Institute of Petrochemical Technology, Yan et al. worked on the optical tomography using optical fiber [26] with an addition of artificial intelligent element in their design. A researcher from Technical University of Opole, Poland used optical tomography in different types of research. The research is concerned with the implementation of optical tomography in a water tank [27] and dual tomography, which was proven could improve the image reconstruction [28].

3. The Selection of Optical Sensor and Projection Arrangement: Advantages and Disadvantages. The selection of optical sensor is crucial in the first stage of tomography. To ascertain that the system will operate efficiently, a comprehensive selection of the sensor must be performed [29]. The selection of sensors is influenced by the projection arrangement of the selected optical sensors. These are parallel beam mode and fan beam mode.

For parallel beam mode, the sensors have a narrow angle beam while fan beam mode uses wide angle beam. Both projection, parallel and fan beam mode have their own advantages and disadvantages. The main difference between parallel beam and fan beam mode is depicted in Figure 2.
In parallel beam projection, the sensor is arranged as one to one basis. Meanwhile, for fan beam mode, one transmitter covers more projection range. As shown in Figure 2(a), the parallel beam projection is simple and easy to implement. This is because all transmitters and receivers will be ‘ON’ in the same time and no switching control is needed in the transmitter part. However, this simple construction resulted in drawbacks as the circular cross section provides poor coverage where the line of light is straight and only certain parts are covered. Blank sport or blank part that cannot be detected will directly affect the tomogram result.

For fan beam mode, the detection coverage is 100% of all part in the circle. However, the vital drawback of this mode is that the switching process of the detectors from one transmitter to another transmitter until the entire transmitter array finished doing the scanning, critically delays the detection period. Investigations were carried out to identify the best detection for optical tomography by coupling different sensor tool to different beam mode. The investigated groups are listed as below:

- a) fiber optic and parallel beam mode,
- b) LED and fan beam mode,
- c) infrared and parallel beam mode,
- d) infrared and fan beam mode,
- e) laser and parallel beam mode,
- f) laser and fan beam mode and
- g) dual mode.

3.1. Fiber optic and parallel mode. The preparation of fiber optic in optical tomography was a challenging job as incorrect cutting procedures will cause fault measurement. Therefore, careful setup of the system is a necessity. Abdul Rahim [1] and Ibrahim [3] have reported optical tomography using fiber optic for measuring different materials.

Abdul Rahim [1] used fiber optic as a sensor tool. The diameter of pipe in his research was 81mm. The light source was a single quartz halogen that provided a large beam area. It produced good illumination for all the optical transmitter fibers, which were arranged in a bundle. The receiver fiber converted the signals to electrical signal by PIN diodes. Although only 16 pairs of fiber optic transmitter and receiver were used and arranged in two projections, it is capable in producing concentration profile and tomographic images successfully. Besides that, this research also performs well in getting the result for particle size distribution. The assumption that is being used to retrieve the results are to ignore the effect of scattering and diffraction of light and the project is specific for vertical flow type [6]. One drawback of fiber optic is that the transmitter and receiver need
to be aligned accurately. Otherwise, the sensor reading will produce incorrect reading and this can greatly decrease the accuracy of the system. Another problem arises would be related to the light collimating issue [15] where the arrangement of transmitter and receiver in a group might create a problem since the possibility of overlapping is higher between adjacent receivers. This results in intensity loss. Although there are negative effect, fiber optics provides the opportunity to design sensors with a wider bandwidth. It also enables measurements of higher speed flowing particles. In his research, the offline method was being used, and it should be replaced with an online approach. It needs some improvement in reconstruction algorithm to obtain a better image as well. Apart from that, the CPU speed and data acquisition need to be improved to make the system more reliable. Furthermore, the detailed investigation of particle size distributions should be carried out and a wide range of sample with different mean diameters and particle size distributions should be used in pressure type pneumatic conveying.

Ibrahim (2000) has put in some enhancement in optical tomography. The fiber optics used in his experiment were arranged in two planes, which was different from Abdul Rahim [1] who used only one plane. Each plane consists of two rectilinear and two orthogonal projections. For orthogonal, 8 by 8 sensors were implemented while for rectilinear, 11 × 11 sensors were used. The total transmitter sensors in one plane were 38 and when it was added to the second plane it becomes 76. The unique feature was the implementation of four 35cm projectors as a light source and light guide, which can provide collimated beams. This research ignores the scattering effect and also neglects the fibre cladding as it is assumed thin in comparison to the central fibre. As result, small bubbles in diameter of 1-10mm and volumetric flow rate up to 1l/min can be detected using optical tomography. The optical tomography is sensitive to large bubbles in water of diameter 15-20mm and volumetric flow rates up to 3l/min [3]. This huge modification produces a result with higher resolution than the previous research done by Abdul Rahim due to the increment in the number of sensors. However, the arrangement of the receiver and transmitter were also in a group and this will result in overlapping beam for the receiver. Some improvement in this research can be done by replacing the combination of online measurement and offline computation, with online measurement. Different forms of filtering technique in reconstruction algorithm should also be investigated in order to produce better result.

3.2. LED and fan beam mode. The best characteristics about LED are the minimal power drawn and its longevity feature. Besides that, it is cheaper compared to many other sensors. LED has slow rise time and fall time, but it can still be used in optical tomography system as was demonstrated by Chan [10] and Zeng [30]. [10,30] proved that LED is feasible for optical tomography applications.

Chan [10] used LED as a source of light and PIN photodiode as a receiver, both with diameters of 2.94mm. The sensor was arranged in a fan beam projection technique and the total amount of sensor installed are 16 pairs as shown in Figure 3. The idea of fan beam method proposed has a larger emission angle of the source that was feasible to be sent to all the receivers and also the emission power is uniform along the projection. He used only one single projection angle and this will take a longer time while processing the acquisition data. There are a few assumptions that had been made which include:

i) Light scattering and beam divergence effect are neglected.

ii) The attenuation factor for air is assumed to be zero while the attenuation factor for solid particle is assumed to be one. All incident lights on the solid surface are fully absorbed.
iii) Single projection resulted in 16 light beams from the emitter towards the photodiodes and each of the light beams possesses a different width, depending on the sensor geometry and projection angle.

Figure 3. Sensor arrangement used 16 pairs of sensor

Zeng et al. [30] chose red LED as the source of a transmitter and in parallel with the light that will be detected by photo valve at the other side. They used rotary working table for the experiment setup to get the complete projection for the object. However, this technique is not suitable for real time application. In this project, they employed one of the optical scattering method, which is light extinction method but ignored the diffraction effect that is formed by the edged of particles. The sand in a diameter of 120μm was dropped through a funnel and the flow velocity was observed to be dependant on the controlled funnel. Thus, by changing the velocity, different optical signal would be obtained. From the experiment, random fluctuation signal was produced, where it was related with the light decrement. As the light decreased, more particles were shown to be passing through, that blocked the light source which is an indication of a higher mass concentration.

3.3. Infrared led and parallel beam mode. Infrared LED has a characteristic of invisible to human eyes, and it is easy to handle like LED. This type of sensing element is recommended since its wavelength is outside of visible light; therefore the interruption of day light can be avoided. Pang [11], Goh [12], Chiam [13] and Dugdale [5] are among the researchers that used infrared in parallel projection for optical tomography.

Pang used infrared LED from TEMIC Semiconductor model TSUS4300 that had a wavelength in the range of 900 to 1000nm, whereas the peak of wavelength was at 950nm [11]. Thus, the optical tomography sensor designed is indisputably unaffectted by the visible light source from the surrounding environment that will result in error during the measurement process. The features of small angle of half intensity, which was 16 degree is a main criteria to take into account because they implement parallel beam mode in their project and it is less costly (MYR 0.91 each). For the receiver, Pang
had chosen phototransistor instead of photodiode due to compatibility of phototransistor model, TEFT4300 to the LED infrared. The advantage of phototransistor was the starting wavelength of phototransistor which was about 875nm. This was well away from the visible light’s boundary, 700nm. Most photodiode available in the market has the same starting value of visible light’s wavelength. It has a physical size of 3mm in diameter, peak of wavelength is 925nm, and angle of half sensitivity was 30 degree and less costly (MYR1.83 each).

For the experiment purposes, Pang used plastic pellets, which look like a small cylinder in dimension of $2 \times 2 \times 3$mm to be imaged. It will be tested to see the flow regimes’ difference in four kinds of regime (full flow, three quarter flow, half flow and quarter flow). To measure the mass flow rate, three other regimes were set up with a diameter of 4.5cm, 4 cm and 3.5 cm. The dropping distance is 16cm and 56cm. The smaller the drop distance, it will produce higher concentration [18].

For the projection technique, Pang selected two orthogonal and two rectilinear projections (16 pairs for one orthogonal projection and 23 pairs for one rectilinear projection). These projections are for the upstream layer and the downstream layer, which had the same projection. Figure 4 shows the projection mentioned.

![Figure 4. Two layer of projection by Pang](image)

This projection method has doubled the amount that Ibrahim (2000) did and this has enhanced the resolution [3]. The two plane arrangement (upstream and downstream) may cause misalignment of objects that passed through from an upper stream to downstream because they cannot be projected in the same layer. This will affect the velocity parameter in this system. Therefore, the distance between two orthogonal and two rectilinear needs to be reduced where the better solution is to make all the projection in the same layer. Nevertheless, this type of projection can successfully determine the online mass flow rate without involving any calibration constant. This work can be contributed to the industrial need because currently there is no tool that is suitable for instantaneous mass flow rate measurement in industry. There is still some improvement that can be done in this research in improving the time to get the mass flow rate measurement and the tomogram image. It is suggested to use a higher sampling rate of DAS card rather than DAS-1802HC. The other alternative is to design the simple and cheaper data acquisition, for example, Ethernet, USB, DSP and FPGA technologies. Furthermore, the computational issue in this project should be addressed, where; it involved four powerful personal computers and a network hub in order to implement data distribution system. This would result in a large and non-portable system. The use of DSP and FPGA chip can overcome this problem.
Goh identified Pang’s problem and applied single plane for the system [12] as shown in Figure 5. It has improved the system by considering that all measurement for orthogonal and rectilinear projection is done in a same axis. Therefore, the measurement is more precise than Pang’s technique. The uses of Ethernet based data acquisition systems was beneficial in assisting a higher data transfer in the solids flow meter system and develop long distance monitoring. However, this work also has a weakness in terms of mass flow rate measurement where a calibration is needed every time new materials want to be tested. Other than that, the circuit became bulky and crowded which could easily cause short circuit. The distance between emitter and receiver were increased that directly affect the intensity of the light and also the image to be displayed. Goh utilized sensor from Agilent, HSDL 4420 as an emitter and HSDL 5420 as a receiver (Ø = 2.54mm). Two orthogonal and two rectilinear projections were implemented. The configurations of the sensors were 16 pairs for each orthogonal projection and 16 pairs for each rectilinear projection.

These sensors have good performance in many ways. Firstly, the sensors operated in the 875nm region which was away from visible light (700nm). Secondly, it can operate with a narrow beam area where its half angle of the full radiation angle is 12 degrees. The selection of a receiver matched the transmitter in terms of spectral, peak sensitivity and size. Goh selected photodiode as a receiver for its faster response in nanosecond in comparison to phototransistor (in μs). Goh discovered that at a concentration percentage of 80%, the flow saturates at the flow rate of 751.99gs⁻¹ [12]. The saturation effect was explained as follows. At lower solids concentrations the mean free path of particle movement is long and the random movement of the solids is not damped by collisions. At higher solids concentration, the mean free path is short and the randomness of particle movement is damped by collisions. A test is performed to investigate the overall timing diagram for the developed tomography system. This is done by setting a resolution of 128 × 128 pixels for the image reconstruction using the interpolation technique in DSBP algorithm. The image reconstruction was processed in 2.70ms and it gave 369.83 frames per second (fps), which is quite competent because the time to complete reconstructing
one cross sectional image is only 2.70ms. Goh used some assumption in her research, where the attenuation factor for air is assumed safely to be zero while the attenuation factor for solid particle is supposed to be one. In other words, all incident lights on the surface of a solid particle are fully absorbed. The light scattering and beam divergence effect are ignored. From the Ethernet link speed analysis, data transfer rate is restricted by Rabbit microprocessor 21MHz CPU speed. It is proposed to use DSP processor, which can operate at the CPU speed up to 400MHz.

Chiam [13] used the same type of sensors and projection method as Pang [11]. Enhancement in the data acquisition unit was done using Hybrid DSP, which is the combination of microcontroller and DSP chip. Standard data acquisition card (DAQ) or modules with similar capabilities would have cost more than RM10000 whereas the developed system only required less than RM2000 for the DSP chip, electronic components and PCB fabrication. His research results and findings are proven to be better than Pang’s discovery. Mass flow rate measurement was produced in 430 ms processing time. The implementation of the new hybrid image reconstruction has increased the quality by 12.5% [21] because the new algorithm reduces the possible errors in image reconstruction of arc shaped object. The processing time to obtain flow velocity is 12 times faster by using sensor to sensor cross correlation in frequency domain compared to pixel to pixel cross correlation in time domain. An assumption for using cross correlation technique for flow velocity measurement is that the arrangement of particles flowing through the downstream sensor layer is a time-delayed replica of the upstream sensor layer. There is some enhancement that can be done in this project where the application of multi-processor based embedded system can possibly improve the performance of the overall system further. Pipelining technology used in CPU design or parallel processing method can be implemented to increase the throughput.

Dugdale et al. showed infrared LED and photo detector managed to produce the tomogram for bubble investigation [4]. Dugdale et al. implemented infrared emitters and detectors to exploit the optical characteristic. Two types of orthogonal arrangement were investigated, which was the $8 \times 8$ and $16 \times 16$ configuration. Small planoconvex glass lens with dimension 5mm in diameter and 8.7mm back focal length was used to acquire beam from the LED. Obviously, by increasing the number of sensors to $16 \times 16$, the resolution would increase, where the configuration of 16 transducers per projection was the optimum hardware design till present. Therefore, further improvement on resolution needs to attach more projections which require new algorithm. In this technique, smaller objects that are below 5.5mm in diameter cannot be detected. Therefore, to overcome this drawback, more sensors should be arranged to make the gap between the light beam decreases as much as possible.

3.4. **Infrared led and fan beam mode.** Leong [8] has applied fan beam mode by using other types of light source; the infrared emitter coupled with fiber optic. The type of infrared was SFH484-2 with wavelength peak at 880nm and small radiation angle of 16 degrees. The small radiation angle was vital as the emitting area needed for the infrared to be coupled with the fiber optics was small and narrow. As for the receiver, photodiode SFH213-FA was used. Two assumptions had been made in his project. Firstly, all incident lights on the surface of the solid materials are fully absorbed by the object. Secondly, the effect of light diffractions and scatterings are ignored because the primary effect is the attenuation of optical energy by particles intercepting the beam. Leong has doubled the number of sensor pair to 32 in contradiction to Chan [10] that only used 16 pairs. Figure 6 shows the sensor arrangement by Leong.
Since the physical size of fiber is small, the effort to double the number of sensors seems to be a very effective technique. However, there is a computational issue that should be resolved first. The present data acquisition card needs the ISA slot for communication. The ISA slot feature is currently not available in the latest generation of Pentium IV computers. It is suggested that the new model, Keithley DAS1802HC, that communicates using the PCI slot should be used. The PCI slot is attainable in many computers and this will help in obtaining a faster image processing rate since the speed of the computer processors in the market can achieve up to 2.4GHz or higher. As an alternative, it is also proposed that specific data acquisition system for process tomography should use Ethernet, USB, or FPGA technologies for cheaper communication.

3.5. Laser and parallel beam mode. Laser is a type of coherent light output, and it has high speed in fall and rise time compared to LED and infrared. The emitting area of a laser diode is smaller in comparison to LED and infrared in the factor of 30000, which means the laser intensity can be approximately 30000 times that of an LED and infrared. However, laser is partially nonlinear and varies with the temperature [31], similar to LED and infrared. In terms of safety, laser diodes are more dangerous and can harm our eyes.

On the other hand, Mohamad [20] proposed a research where the objectives are to produce a cross sectional images of a flame. This is accomplished by using the laser Neon as the source of light, where it illuminates the fiber optic causing the light to flow through it. Eight pairs of transmitter and receivers were utilized to be applied for two orthogonal projections. The use of fiber optic could perform well since it produced perfect collimation. The developed system had been tested by locating a cylinder object with a
diameter of 3mm in the pipe with an image plane [9]. For flame testing, two models were tested; the half and full open. The study showed that, for half open the concentration was higher because of the flame intensity was higher and not because the larger size of the flame. During full open operation, the result was lower in concentration. In this project, the flame image generated from the image results is not shown in an accurate manner. Hence, for future consideration, this can be improved by utilizing appropriate sensitivity maps and image reconstruction algorithms.

3.6. Laser and fan beam mode. Chen et al. [22] adopted the medical tomography technique (optical computed tomography) in their process industrial research. The used of near infrared laser diode was assumed to have moderate water absorption. This was suitable for the parameter measurement of two phase flows. The advantages of sensor selection are the compact structure and also its high frequency. The projection in this research was based on parallel scanning and serial receiving which can avoid the disturbance of optical reflection and refraction effect. Six NIR diode lasers and 48 NIR diode sensors worked as receivers where the wavelength for diode laser was 780nm, beam diameter equal to 1mm while the power output was 10mW. The scan sector for the emitter contained 24 receiver sensors. Therefore, one scan cycle collect 144 projection data. The resolution of the system could easily be changed from the mm level to the μm level and it was done by changing the laser beam diameter and sensor density; therefore, it increased the flexibility of the measurement. The researchers concluded that the more emitter involves, the more projection can be produced and this can directly increase the resolution of the image. Three factors that influence the system response speed, including the speed of scan of the emitter, the speed responds of the receiver and the operation speed of the image reconstruction algorithm. Since their system covered all these factors, clearly the system had a high responding speed. Yan et al. [26] used 8 optical fiber sensor units and each unit comprises of three optical fiber collimators, one photo detector and one optical window. The source was the 1310nm laser diode (YSLD3115) with the power of about 1mW while the type of detector was YSPD-TO20. The beam width was less than 1mm. Each unit emitted and accepted three rays from the adjacent units in counter clockwise. They consider the effect of optical reflection, refraction, scattering, absorption and light radiative transport theory. The pixel was constructed into 4 sections and all in concentric circle shape. This system can be easily adjusted by changing the collimator’s direction and the wavelength of optical source according to the refractive index of the measured medium. The unique feature of their approach was the implementation of Genetic Algorithm in their image reconstruction algorithm. However, since there were only 60 pixels for the whole pipe, the image reconstructed was not accurate. Rubber was used in the experiment and found that the small opaque object would not be detected if it is absent from the light path. As for solid object, no matter how small it is, it can be easily detected as long as it blocks the ray. The position of the object with the size of several pixels can be accurately reoccurred but some reconstructed errors in its local area were produced due to the non-transparency of the solid medium. The pixel plane was non-uniform with the measured information, where the same object would have a different reconstructed image. From the above statement, light can still go through the opaque object but not for the solid object. One of the weaknesses of optical tomography is; it cannot detect the object that was located behind a bigger solid object because the ray cannot go through the solid object. Zheng et al. [24] did a research on optical tomography to measure concentration profile and mass flow rate. The system consists of an array of laser diode sources and photodiode as a detector. Zheng et al. manipulated fan shape beam projection and divided 3
structures of an array which consists of 4 sources 15 beams, 8 sources 15 beams and 15 sources 15 beams. The outcome showed that 15 light source and 15 beams produced the smallest Space Image Evaluating (SIE) which was 7.67%. SIE was based on error theory in science measurement where the grey values in original images are subtracted from reconstructed image. The result was then divided to grey values of the original images. It showed good performance in SIE but with the largest computational time of 0.99ms. The computational time was higher because they used a large amount of sensors and therefore more time was needed to rotate each of the sources. The experiment aimed to reconstruct the concentration distribution and validate the relationship between the optical attenuation (projection sum) and the mass flow rate. Zheng et al. has calibrated the measurement coefficient K at different screw feeder speed. From there, the relationship between mass flow rate and projection sum was linear. Although the highest spin speed of screw feeder was used, the mass flow rate was still low which were 34.20g/s. There are a few assumptions for this research where, the particle velocity is constant and measuring environment, physical and chemical features of the particles are kept invariable, so the calibration coefficient is approximately a constant.

Zhang et al. [23] enhanced the works done by Chen et al. [22]. New approach was implemented which was based on Terahertz process tomography. Near infrared (NIR) prototype system has become the simulator of terahertz tomography because the wavelength of NIR is near to Terahertz’s. All the projection used was the same with Chen. The absorption effect was tested on a circle diameter of 50mm. Three opaque cylinders with diameter 3mm, 5mm and 7mm were used. This arrangement was the same as Chen’s studies. Terahertz has a characteristic of quasi optic features like visible and infrared too. Therefore quasi optic scan model can be used in Terahertz system, and it was more stable and simpler in comparison to X-ray process tomography. The set of Terahertz sources and receivers were distributed uniformly around the pipe and the amount of sensors was depending on the pipe diameter. The static scan mode used in their research was able to produce an appropriate respond of speed. Terahertz is depended on the complicated and expensive ultra-fast laser system and it is costly. Therefore, the combination of micromachined Terahertz with a silicon photonic band gap backing plane will make it possible to lay out an array of Terahertz detector into a CCD mode which is cheaper.

3.7. Dual Mode Tomography. Mohd. Zain [14] and Rzasa [28] in their research both used optical fan beam projection combined with electrical capacitance tomography. However, due to the difference in the vessel conditions, the optical projection differed from each other. Mohd. Zain focused on vertical while Rzasa in horizontal measurement. Mohd. Zain only used single projection while Mariusz used 5 projections to cover the cross sectional area inside the vessel. Mohd. Zain used 16 pairs of optical sensors, and the type of sensors is similar with Chan [10], that has 5mm in diameter. Rzasa used 64 phototransistors as a detector with 5 light sources from the 55W bulb. Rzasa designed 5 planes with 7mm distance from each other while Mohd. Zain uses single plane. Both researchers agreed the joining images of optical and electrical capacitance tomography will gives a better resolution in final image reconstruction.

3.8. Summary. According to previous researchers, Leong [8], Chan [10] and Chen et al. [22], fan beam technique gives better performance in comparison to parallel beam. Parallel can give a limited number of measurement and this will make the resolution lower. To improve the performance of parallel beam projection, Muji et al. made a combination between fan beam and parallel beam [32]. This configuration had been proven can improve the resolution. However, in terms of speed, the reputation is lower due to many measurement that has to be counted. Therefore, the solution is choosing
the sensor that have a good respond. In terms of sensor selection, the majority of the researchers used optoelectronic device because it is easier to handle than the fiber optic. Laser diode is preferred because of its collimation factor and narrower beam of light. Meanwhile, infrared emitter is chosen because of its safety features towards human eyes in comparison to laser. Chan [17], Pang [11], Goh [12] and Chiam [13] agreed that there were three methods that can influence the collimation of light, which were, first, the sensor to be used must have a small view angle. Second, no divergence of light between adjacent sensors should occur; the stopper or aperture must be located in front of the sensors. Third, the alternate arrangement between transmitter and receiver can avoid the light from overlapping with each other. The selection of sensor must meet up certain criteria: all incident lights on the surface of an object are fully absorbed by the object and light scattering and beam divergence effect are neglected [18]. Other criteria like low cost, small physical size, luminous intensity, high setting time, high transient characteristics, projection angle and wavelength must also be taken into consideration [19].

4. Image Reconstruction Algorithm. Image reconstruction algorithm is important to produce an accurate image. The reconstruction algorithms can be classified into two big groups, namely, Finite Series Expansion and Transform method. In Finite Series Expansion method, the image reconstruction is slower than Transform method [33]. Therefore, Transform method was always preferred by researchers in process tomography. The difference between these two groups could be reviewed in [34]. To make sure the image produced is clear and accurate; a researcher should determine a practical image reconstruction algorithm for their system. Otherwise, the image will not meet the requirement.

Basically, there are three major tomography techniques [35], particularly transmission tomography (example: optical [1] and ultrasonic tomography [36]), diffraction tomography (example: ultrasonic tomography [36]) and electrical tomography (example: Electrical Capacitance Tomography [37-39], Electrical Impedance Tomography [40-42] and Electrical Resistance Tomography [43-45]). For optical tomography the suitable algorithm is a direct method; for example, Fourier inversion and Filtered Back Projection while for Iterative method, the example is Algebraic Reconstruction technique. In Iterative manner, the function of reconstruction formula is simple and will be repeated to get the exact image [46].

Other imaging technique that was introduced by Miyazaki et al. [47], can be implemented to get the clearer image from the tomogram result. The image reconstruction technique used by Zhou et al. [48] can also be modified to suit it with tomography system. Meanwhile, by using region energy and approach degree, the fused image exhibits good infrared target features as well as clear visible background [49]. This is also the good technique that can be explored while using the infrared sensor. Huang et al. [50] made a suggestion on the use of semi-supervised label propagation in image retrieval. The use of only a labeled set or unlabelled set itself will both give the drawback effect. Semi-supervised learning addresses this problem by using large amount of unlabeled data, together with the labelled data, to build better classifiers.

4.1. Linear back projection algorithm. Back projection method is the popular method used by many researchers. Abdul Rahim in his research used back projection algorithm based on sensitivity maps [51]. The sensitivity maps are related to the beam path within the pipe. Here, the pipe is projected onto a rectangular array of 16 x 16 pixels. Pixel outside the pipe would not contribute to the measurement.

Mohamad focuses on Linear Back Projection (LBP) method to produce the concentration profile from the cross sectional image of the flame. LBP is time efficient to obtain
the concentration profile for the cross sectional area. Mohamad used $8 \times 8$ sensors pairs, therefore, the size of pixel becomes $8 \times 8$ pixels [20].

Dugdale et al. [4] used back projection algorithm to reconstruct an image of the pipe cross section. The beam width was 5mm but the width of the detectable beam was only 2mm and the spacing between arrays was 15mm.

4.2. Modified back projection algorithm. Ibrahim [3] used Layergram back-projection (LYGBP) to reconstruct the image. Then a hybrid reconstruction algorithm would be combined with LYGBP to improve the image reconstruction to produce concentration profile.

Pang in his research, used Hybrid image reconstruction algorithm that could prevent an ambiguous effect or smearing effect [11]. Hybrid becomes the makeup of Linear Back Projection. There were $16 \times 16$ pixels that will be evaluated, which is the same value with the configuration of sensors in the orthogonal projection. The rectilinear projection is applied to make the object clearer and apparent.

Hybrid reconstruction algorithm which originated from the linear back projection algorithm was implemented with some improvement in [21]. They made a different approach by dividing the pixel into five smaller parts. Each of the parts could be set as valid or invalid during concentration calculation and not using a whole pixel for the concentration value. By doing this, more accurate object can be defined since there were only 12 probabilities of the shape of image that could be detected. Two small sticks (6mm diameter), medium sized pipe (2.7cm diameter) and a large sized pipe (4.24cm diameter) were used as samples to be imaged. The results are shown in Figure 7.

![Figure 7. LBP algorithm](image)

From Figure 7, each sample was shown with image reconstructed using Hybrid algorithm on the left and LBP algorithm on the right. The two pixels shown in the first image represents the two small sticks. The second image seems like four pixels due to ambiguity.

Zeng et al. [30] used back projection routine and planning to add a filter modulation to every projection before the reconstruction to reduce the blurring section. They claimed that to get the better articulation of the image, every pixel that represents a volume unit should be smaller than the resolution but the volume unit selection was limited by the light source and the detector performance. There is a room for improvement by comparing the tomogram with the object. This could be useful to the researchers for evaluating their selected technique performance.

4.3. Comparison of algorithm with other algorithm/technique. Leong in his research tested two kinds of algorithms; Linear Back Projection and $10^{th}$ Iteration. Based on his research, he found that 10th Iteration method seems closer to the calibration graph
of a percent flowing versus average Mass Flow Rate. He concluded that 10th Iteration method provided more accurate image than LBP [16]. However, only 24 fps can be obtained for LBP and 4fps for reconstruction using 10th iteration. This means although 10th Iteration can give more accurate result, the speed is lower than LBP. Before the measurement, the mass flow rate will be calibrated manually. The result shows that only 40% flow was linear up and this is approximately the same with the calibration method that contains just 50% flow that linear up. 10th iteration shows a better result where 40% flow obtained 1179.454g/s in comparison to LBP, which obtained 1171.3g/s. The iterative reconstruction algorithm has proven to produce more precise images by eliminating the smearing occurred in LBP images. However, reconstructed images were observed to need longer image processing time as the number of iterations increased. Therefore, a new iterative scheme that can reconstruct images of the same quality as an iterative method while maintaining equal image reconstruction speed as the LBP method should be used.

Chan made a comparison of six types of algorithm; LBP, filtered back projection using full flow model (FBPF), Filtered Back Projection with 1/r function (FBPR), convolution back projection Ramp (CBPR), convolution back projection Sinc (CBPS) and Graphical Back Projection (GBP) to perform the image reconstruction [10]. He also tested six algorithms that combined with HRA (hybrid reconstruction algorithm). Chan had considered four flow models namely, single pixel, multiple pixels, half flow and full flow. The obtained concentration profile shows the accuracy of information regarding to the object space in the investigated area. Based on his experiment, he had chosen 2 types of algorithms: a pure GBP and the combination of FBPF with HRA. GBP is chosen because it is the fastest reconstruction algorithm and has acceptable quality compared to LBP. The merged of FBPF and HRA are suggested to be used because the accuracy of reconstruction and acceptable processing speed for concentration flow condition. Both algorithms are in resolution of 32 x 32. Figure 8 shows the tomogram of pure GBP and FBPF with the combination of HRA.

![Figure 8. Image of (a) pure GBP and (b) FBPF + HRA](image)

Mohd. Zain, as mentioned before, had done dual mode tomography, which is the combination of optical and capacitance. For Optical tomography, Mohd. Zain made a comparison between LBP (0 iteration) and iteration (greater than 0) method. Here, 128 nodes and 512 x 512 pixels resolution were used [14]. Mohd. Zain found that after the
10th iteration, the fidelity of the images starts to deteriorate constantly. This happened because there was a large difference between the projection measurement of the images produced and the actual measurement. Therefore, his result proved the result obtained by Leong [8].

4.4. **New algorithm.** In research by Goh, each rectangular consists of 16 × 16 pixels for image resolution of 256 × 256 pixels [12]. The Dynamic Sensitivity Back Projection (DSBP) had been applied in her research. And for smoothing the image, Goh used interpolation technique. Therefore, this technique was applied together with DSBP. DSBP check the dynamic sensitivity instead of applying a sensitivity map in a previous algorithm like LBP. DSBP algorithm can improve the system accuracy and image quality in comparison to the other back projection algorithms [12] due to its ability to reconstruct a fine image (refer to the image that have a size smaller than a rectangular in the image plane). Figure 9 shows the different in image tomogram by using different image reconstruction algorithm where, %C is a concentration error and peak signal-to-noise ratio (PSNR) is an error measurement in color image processing. The typical PSNR values range between 20 and 40.

![Figure 9. Image of different image reconstruction algorithm](image)

Yan et al. [26] used genetic algorithm which was based on the natural selection and evolutionary process, and it involved 60×100 matrix. Each of the matrices was represented by 0 and 1 bit. For this method, there was a 300 of an iteration of the process that needs to be executed. Therefore, this technique seems complicated but produced an accurate result.

Chen et al. [22], design 25 × 25 pixels in their research. They used two value filtered back projection algorithm, which is the finite logic operation that is simple and fast. This algorithm is ideal for simple two phase flow, but was not appropriate for complicated distribution or complex shape two-phase flow. This algorithm is low in accuracy but very excellent in terms of speed. Chen et al. simulated three opaque cylinders in diameter of 3mm, 5mm and 7mm diameter in a 50mm diameter circular area. The result that they obtained was based on computer simulation. Zhang et al. [23] used the same algorithm as Chen et al.

Zheng et al. [24] choose the least square algorithm with constraints (LS) to reconstruct the object field distribution. The number of total pixel was 15 × 15 for different fan-shaped methods. Their project was able to identify the complicated object field shape and this is the advantage of their project compared to others.
4.5. **Summary.** In conclusion, the majority of the researchers used LBP as the core of their image reconstruction. Abdul Rahim [1], Mohamad [20] and Dugdale [5] used pure LBP. Four of the researcher used the modified LBP with other technique such as LYGBP by Ibrahim [3], Hybrid as did by Pang [11] and Chiam [13] and Filter Modulation as did by Zeng et al. [30]. LBP can produce very fast speed images but in terms of resolution it is not very accurate. By combining LBP with other algorithms that have their own advantages, the speed and the quality can be enhanced. Some of the researchers also made a comparison between LBP with other algorithms. Others that used new algorithms include; DSBP by Goh [12], genetic algorithm by Yan et al. [26], two value filtered back projection by Chen et al. [22] and Zhang et al. [23] and least square algorithm with constraints by Zheng et al. [24] which they proved to produce a good quality image.

5. **Conclusion.** The selection of sensor is highly significant. It greatly influences the overall performance in the tomography system. Low cost sensor is an element to be deliberated by nearly all researchers since some suitable sensors are competent to produce the same performance as some high cost sensor by implementing appropriate circuit design. Types of projection were also considered as the major factor in acquiring good results. To deliver a high performance tomography system, accurate design is crucial. Sometimes, more projections required more time in processing. Little projection can reduce processing time but produces lower resolution images. Therefore, a balance between time and resolution should be accomplished to get an ideal optical tomography system.

**REFERENCES**


