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EMERGING RESEARCH ON PROCESS TOMOGRAPHY

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PREFACE

There is a widespread need for the direct analysis of the internal process plants in order to improve design and operation of equipment. Process tomography involves using tomographic imaging methods to manipulate data from remote sensors in order to obtain precise quantitative information from inaccessible locations.

This book discuss on Emerging Research in process Tomography and its application. It's very useful to the process engineer and researcher in this area.

I would like to express my appreciation to all researchers in research focus group - Instrumentation and Sensing Technology (INSET) Universiti Tun Husssein Onn Malaysia and Process Tomography Research Group (PROTOM), , Universiti Teknologi Malaysia

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CHAPTER 1
Process Tomography

1.1 Introduction of Tomography System

Tomography system is one of the methods that had been used to construct cross-sectional image from data obtained by the system. [1] Basics concept of tomography is to determine the distributions of materials by obtained the data using sensors that distributed around the periphery of pipeline. [11] Tomographic imaging system designed to analyze the structure and compositions of objects by examining them with waves or radiation and by calculating virtual cross sections through them. [5] Tomographic sensing instrumentation also helps us to visualise the internal characteristics such as to measure the concentration, velocity, mass flow rate, and particle sizes distribution. [11]

Tomography method is widely used in medical application before it spread into industrial application. In medical fields, tomography has proven its capability to detect tumours. [11] Positron emission tomography can detect existence of oesophageal and gastroesophaeal junction's tumours. [47] Impedance tomography is one of the tomography methods that applied in medical field. This method is imaging the distribution of conductivity or permittivity volume inside human body. Impedance tomography is used in medical area because this method is safe, simple application, high speed data collection and has possibility to characterized tissue and other particles in human body. [30] Another approach of medical tomography system is by using optical coherence tomography. Optical coherence tomography technique is non-invasive and non-intrusive technique where this method can generate two dimensional and three dimensional tomographic images with micron resolution. [46]

Then, tomography method was applied in industry and it is known as process tomography. Process tomography mostly applied in mixing process, multiphase flow, batch process monitoring, and many more. [11] For an example, the impedance tomography system also had been used in process tomography to detect particles in flow measurement system. The types of sensor still the same but the orientation of sensors is difference. Some of process tomography system is developed in using wireless local area network for data processing. This wireless system had help to reduce the noise effect that can cause low quality of image reconstruction. [30] Process tomography system should be robust and can perform well in aggressive environment which contains flammable superheated or corrosive materials and high internal pressure. [35]

1.2 Development of Tomography System

The development of tomography system divides into three segments where there are sensors, data acquisition system, and software. [6] Tomography system has two main components which is hardware part and software part. For hardware its contain sensors, signal or data control, while software contain signal reconstruction display. [1] For hardware, the right choice of sensors is needed because sensors is the main part in tomography system and it is chosen based on the types of particles or objects that we want to measure whether it is liquid, gas, or multiphase mixture. [1] Sensors perform indirect measurement of the image by detecting the radiation with which the object examined. [5] The signals from sensor usually being amplified, filtered, and multiplex before it send the data to the computer. [22] There are two types of sensors, hard-field sensor and soft- field sensors. For hard-field sensors, the sensitivity is independent of parameter distribution inside the sensor while for soft-field sensors; the sensitivity distribution inside the fields depends on the parameter distributions. [22] The example for hard field tomography system is gamma tomography method and X-Ray tomography method. For these two methods there are so expensive methods and required special attention to safety. Electrical tomography system is the example for soft field method. [49]

Different types of tomography consist of different type of sensors being used. One type of tomography system which is ionising radiation can gives high resolution image. X-ray computed tomography system is suitable for off-line process because it is bulky while gamma radiation is one method for real time process tomography. It is suitable to used optical tomography system to measure transparent liquid or fluid. Electrical resistance tomography is suitable for process that does not have electrically insulating boundary while electrical capacitance was inversed. [1] Electrical capacitance tomography system has three difference subsystems; DC offset compensation, AC feedback compensation, and self-balancing. All these three subsystem have their owned advantages and disadvantages.[29] Tomography system that used capacitance, resistance, and inductance are known as electrical tomography system and these electrical tomography system is non-intrusive and low cost, no radiation hazards and easy to implement.[3] Besides that, electrical tomography system is rugged and robust to cope with industrial environment.[28] This type of tomography system also suitable for real time imaging system because it have high speed capability.[28] To measure the density properties of distributed phases, ultrasonic tomography is the right choice. [1]

Sensor configuration also important parts to be investigate. There are many types of projection patterns that that being used in tomography field to detect the flow materials within a pipeline. In optical tomography, there are two types of projection beams, parallel beam projections and fan beam projections. For parallel beam projections, the sensors are in a straight line and the view angle for each should be small enough. [25]

1.3 History of Tomography System

Development of tomography system already started at 1950 in medical field. In 1990, process tomography becomes important part in industry. At that moment, the requirement of instrument that robust, non-invasive, and can operate with fast moving fluid is highly increased. Data that obtain from process tomography system can be used to reconstruct an image that can give the information on flow regime, velocity and concentration of components on pipeline. [2]

In the middle of 1980, electrical impedance tomography developed for imaging human body because it safe and low cost. The difference between medical tomography and process tomography is the type of object that the system measured. For medical tomography, it aims to measure the locations of objects in space where process tomography needs to measure both locations and velocity of movements. [2] Medical tomography and process tomography also produce different quality of image reconstruction. For medical tomography, it gives good image reconstruction compare to process tomography. It is because process tomography deal with high level of noise. [12] Besides that, tomographic reconstruction in process applications has been more quantitative than qualitative in real world. In order to minimize this problem, some researchers had developed and applied process tomography system as a sensor for optimal control. In this case, they applied feedback control such as proportional–integral controller, proportional –integral-derivative controller and linear quadratic Gaussian controller with tomography system. The controller is based on a sequence of stationary images produced by process tomography. [15]

There are four generation of tomography system. First generation consists of source which emits a linear beam radiation sources. While in second generation, the detectors is placed opposites to a set of radioactive sources, sometimes the sensors moving around the objects measured, and numbers of receivers is equal to the numbers of transmitter. For third generations, various types of detectors being used and fan beam projection is introduced. [35] The last generation is called the fourth generation where tomography system should be fixed and no need to move their transmitter and receiver around the objects. [36]

1.4 Applications of Tomography System

Process tomography is an important method to be used in an industrial plant. [3] Many industries such as power generation, food processing, paper and plastics productions, and solid waste treatment deal with gas or solids flow measurement. [13] Process tomography system is useful for plant control because the ability of this system to measure concentration, identify phase size and boundaries within vessels and pipeline. This technique is non-invasive system and non-intrusive system where it is not applied directly to the object that want to measure and the nature of object also not being touched. [2] Process tomography system also helps to solve the problems that caused from gas or solid flow measurement system. The problems that usually occurred are cause by solids fraction profile, flow regime, opacity, intrusive, blockage and velocity. [13] The development of powder technologist also based on the important of process tomography system where this method becomes the important tools for monitoring particulate structures and moving particulates structure. [14]

Most of process tomography system is used for online control and monitoring purpose because of its capability to produce data for internal characteristics of chemical engineering process. [3] This process tomography system widely used in chemical engineering process such as bubbles columns, fluidised beds, pneumatic transport, liquid mixing, cyclonic separation, pressure filtration, liquid pipe flow and many more. [3] Most of the used of tomography system in chemical engineering is for qualitative and quantitative analysis and fault detection process where this method can produce three dimensional visualisation in real time process. [6]

Process tomography involved in two different types of systems which are on line and off line systems. For on line system, data captured should be fast and data processing time also should be fast while for offline system data captured should be fast but data processing time can be slow. [3]

Process tomography system can be found in single modality system and dual modality system. Single modality system means only one type of sensors involved in measurement. Single modality system cannot work to measured multiphase flow or this system still can captured multiphase flow but produce a low quality of image reconstruction. For multiphase flow, dual modality tomography system is introduced. But, this multi modal tomography system has certain requirement to make it work smoothly. The synchronization in two modality data acquisition is required. Besides that, multi modal tomography system should be fast, standardized, flexible to adapt the difference processes, and can integrate into one measurement system. For this multi modal tomography system, the good software is needed because software acts as main controller to control and communicates with each modal unit via the communication link. This software tools play an important part to achieve central system management for multi modal system with advanced data processing and visualisation. [24] Multi modal tomography systems also help increased the speed of monitoring image, and this approach is really needed by today's industry for optimization and troubleshooting requirement. [35] Multi modal tomography system usually used in chemical and biological process industry that used multiphase flow systems. In this of industries, the flow structure is complicated because it involved micro-scale and macro-scale. [50]

1.4.1 Tomography System in Chemical Engineering

Process tomography also had been used in oil industry for multi-phase flow measurement system. Oil industry faced with difficulty to measured complex mixture of gas, oil, water and other components such as sand. [7] Besides that, oil reservoirs were totally different compare to each other because it based on the location and the edge of wells. [10] Conventional approach that usually used to measure this complex of mixture oil is using single phase flow meter where the mixture need to separate based on it characteristic by using separator. The problems occurred because some of separators are bulky, high installation cost, and considerable maintenance and some of them have limitations and can only deal with homogenous flow. [7] These oil industries really need the instrument that accurate for each phase, non-intrusive, reliable, flow regime independent and suitable for use over the full components fraction range. [10] Process tomography system is the suitable measurement system that can be used in oil industry which is deal with complex process. More than one type of process tomography systems can be used to produce an accurate data for image reconstruction. [8] There are varieties of sensors in today's market and each of sensors has its own ability to measured different velocity profile and different phase distribution. [9] Combinations of different process tomography techniques can help multi-phase measurement industry to identify various flow patterns and boundaries [9]. Besides that, the image reconstruction from process tomography application also will be improved. [9]

Some process industry deal with gas-liquid phase or gas-liquid-solid phase. Bubble column widely used in this type of flow measurement system. Usually chemical, petrochemical, biochemical, and environmental engineering use bubble column in their field. They used bubble column for certain operation which deal with air and liquid such as petroleum refining, hydrogenation, oxidation, crystallization, fermentation, coal liquefaction, wastewater treatment, and air pollution control. [32]

Another application that used tomography system is monitoring carbon dioxide storage. This method is used by monitoring the image reconstruction that produces from sensors applied in the carbon dioxide storage. From the image reconstruction, operator can control the amount of carbon dioxide reaction by monitoring from control room. This is very important part for reducing greenhouse gas emissions from spread into our atmosphere that can pollute our ecosystem. [17]

1.4.2 Tomography System in Geophysics

Tomography also widely used in geophysics field especially for seismic depth imaging. The method that had been used was known as ray based post migration grid tomography. Seismological tomography deals with the problem related to travel time residuals defined as differences between the observed and calculated arrivals time. [31] The huge data captured by seismic tomography contributes inconsistencies and errors in data results from incorrect coordinates, errors in timing acquisitions, and error in merging procedure. [31] The evolution in seismic tomography area has solved many problems that occurred based on this old method of tomography. For an examples, the improvement in seismic tomography have help increased the resolution from few thousands meters to a few hundred meters, strategy of working also change from long wavelength to short wavelength solutions and the image quality also improved. Grid tomography system is very important to monitoring requirement of land and ocean bottom cable. [16]

Local earthquake tomography also becomes the most important application that being used in seismic network. In local earthquake tomography, the accurate exact data of location is needed. Unfortunately, seismic tomography face with many problems related to the accuracy of data such as network geometry, arrival time accuracy and presence of noise. To solve this problem, some researchers have introduced double difference seismic tomography method which deals with new algorithms and calculation related to both absolute and relative arrival time. [21]

Process tomography not only used in industrial, but also use in landslide analysis. Landslides analysis is very important especially after tsunami tragedy that killed hundreds of life and destroyed human infrastructure. Due to this case, fluidization process in submarine landslide analysis is very important to study. Computer axial tomography is used in this physical area to study the instability of slide. Computer axial tomography helps to reconstruct an image of the soil-water interaction that can cause landslides. A landslides investigation is very important to monitoring the influence of water circulation on the motion of landslide by producing an image visualisation. Submarine landslide is one of the factors that can cause tsunami and earthquake that can give great destroy to coastal population and infrastructures. Computer axial tomography is the right choice of sensor for soil science analysis, sedimentology analysis, and coal geology or rock mechanics because it is non-destructive technique. In submarines landslides case, computer axial tomography can provide image before and after shearing for clayey soil which is very important information for analysis. [38]

Acoustic tomography method is another method that applied for river discharge monitoring because it is the procedure to control water resources. Usually, horizontal acoustic Doppler and acoustics velocity meters are used to measured stream flow. But these methods have disadvantage where only limited number of velocity sample can be distributed in cross section of river stream. [41] Acoustic tomography system work based on ultrasound detection and illumination to reconstruct image from data captured. [40] This tomography method has ability to measure river discharge even under floods, high turbidity concentration, and high noise level. It is because this method is non-destructive system. [41]

One of the successful applications of tomography system is being used in an atmospheric science field. The tomography system is known as OSIRIS which is the combination of visible optical spectrograph and infrared imager. The main used of OSIRIS in open satellite is to observe the important process in atmosphere that can cause global warming. [19]

1.4.3 Tomography System in Botanical Field

Botanical field also realised the important of tomography method nowadays. Many experiment based on the properties of soil, root, leaves, wood are carry on using tomography method. This is because tomography system is non-invasive. Optical Coherence tomography had been used for investigation of wood finishes. This study is important for investigation related to heritage artifacts. Optical tomography system has the ability to detect layer thickness and can reconstruct the image of wood below the varnishes. [20]

Electron tomography is one of tomography method that more than half century that had been used for plant thylakoid membranes analysis. This method is used to investigate the complex structure and organization of chloroplast thylakoid membranes. This method has possibility to produce a three dimensional image in electron microscope on nanometre scale. [44] Tomography method that using ion beam scanning electron microscope is one of the powerful methods for characterization of three dimensional of micro and nanostructures. [48]

X-Ray micro computed tomography also can be used to visualise plant leaf structures. In early edition of plants leaf structures analysis, researchers used confocal microscopy. But this method has limitation where it only can view limited size area and high transparency of leaf. Sometimes, they need high refractive staining agents to enhance the contrast of leaf. By using X-Ray micro computed tomography system, it can give precise of image visualisation and right quantification of internal structures in three dimensional. Besides that, the advanced of computer software had help to increase the quality of image reconstruction until the characteristics of leaf such as the porosity, connectivity and surface area can visualise in three dimensional. [39] X-Ray computed tomography also can be used for root–soil interaction study. This is because this method is non-intrusive method so the components of the roots and soil are not disturbed. X-Ray computed tomography method also provide the image of nature root growth in different types of soils. This study helps to improve the development of botanical sector. [43]

For soil textures image reconstruction, electrical resistive tomography is the suitable method. Electrical resistive tomography has the capability to detect stones and tillage effects in soil.

This measurement is important to check the fertilization of soil for gardening. This tomography method can check soil texture, bulk density and water contents. [42]

Industrial pulp mixer use electrical resistance tomography to check the mixing quality and quantity in vessel pipeline. Tomography method is suitable method because it is non-invasive and non-intrusive method. Industrial that deal with pulp mixer really needs tomography method to control the quality of their product in controlling consistency of pulp processing. If good mixing cannot be control, surely operation costs can be higher due to unstable production and poor product quality. The way that tomography method controls the mixer is by given an image reconstruction of mixing product. From the image captured, operator can monitor the quality of the mixing pulp by analysis the concentration of the image data. For an example, image reconstruction that show the wide area of lower conductivity indicates higher concentration of chlorine dioxide while small regions of low conductivity show lower concentration of chlorine dioxide. [45]

1.4.4 Tomography System in Powders Engineering

Other application that used tomography system is in powders engineering. Electrodynamics tomography system had proved its capability to captured velocity and mass flow rate profiles of dry powders in a gravity drop conveyer. [27] For powder engineering field, method to measure the velocity of particles is based on the transits times of particles from upstream of electrodynamics sensors to downstream of electrodynamics sensors. [27] Tomography system also used for structure characterization of metallic ceramic composite foam. In this case, computed tomography system is used to examine the composite of foam, porous structure and analyse the geometry structure of the foam. By using tomography system, image of three dimensional can be illustrated. [34]

1.4.5 High Voltage Tomography System

Based on the improvement of study in tomography area, new development which is known as high voltage electrical capacitance tomography had being introduced. This is one of the success achievements in tomography research where tomography system can be applied for large equipment. Some industry deals with very large equipment's and all this equipment still need to be monitored. Process reaction that happened in large equipment's generally changes very slowly and faced with huge noise from many possibilities. So, high voltage electrical capacitance tomography was developed by researchers to deal with this problem. Usually the new development always need some improvement where the image reconstruction from this new invention still facing with low quality of resolution. [37]

1.5 Image Reconstruction

The meaning of image reconstruction is to combine an image by using the data obtained from sensors that captured the image of object measured at different angles and views. [26] To obtained final images, appropriate algorithms are applied to solve equation and reconstruct virtual cross section. [5] There are three methods for image reconstruction, linear methods, iterative methods, and heuristic methods. Linear method is the simplest and quick method compares to the others methods. Linear back projection is widely used in linear method but this method produce poor image reconstruction for analysis. This approach is used in early stage of medical tomography. [22] Linear back projection produce blurry image and hard to captured scattered images. Usually, filtering is applied in this algorithm to enhance the image reconstruction. This common algorithm is known as filtered back projection algorithm. [26]

For nonlinear iterative methods, it is not suitable for real time image reconstructions because the computational load makes them too slow to process the data. But, this method is easy to model and can handle projection noise. [22] The basic concept for iterative method is to discrete the image into pixel s and treat each pixels as an unknown. [26]

Heuristic method can be linear or nonlinear. This method is based on the relationship of trained images and measurements images. [4] Image analysis mostly based on pixels value. Simple image analysis base on mean, minimum, or maximum of pixels values. These pixels values give information related to concentration, filling fraction, or packing density. [4]

Reconstruction technique for tomography system is known as inverse problem. [22] Inverse problem can divide into two different part, estimation components and appraisal components. For estimation component, the reconstruction image is based on data received. While for appraisal components, it based on the relationship between estimated model and actual model. [18]

Some researchers state that, to improve the quality of image reconstruction, the numbers of sensors that being used should be improved in a way to increase the number of data obtained.

[22] Another approach to improve the quality of image reconstruction is by improving the reconstruction algorithm so that more information could be extracted from existing data. [22] Besides that, new development such as neural networks and binary optimizer should be investigated for the use of image reconstruction. [23] Some sources said that the low quality of image reconstruction is because of the limitation of radial and angular sampling of image sliced. In a way to conquered this problem, sinusoidal Hough transform was created by researchers. [33] But, there are still limitation occurred cause by another part such as computational cost, execution time, and limitation in real time capability. [33] More research need be studied in a way to solve the image reconstruction problems.

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CHAPTER 2

Electrical Resistance Tomography (ERT)

2.1 Introduction

Electrical resistance tomography also being recognize as electrical impedance tomography. The main purpose of electrical resistance tomography is to reconstruct an image base on the resistivity distribution of material inside process vessel or pipeline. [54] Electrical tomography system is a system that based on electrostatics fields for imaging the conducting or dielectric properties of an object. [73] In electrical tomography, there consists of three different methods; electrical resistance tomography, electrical capacitance tomography, and electrical inductance tomography. Electrical resistance tomography is widely used in process industry, geophysics field and construction sector. The basics fundamental of this system is base on the value of conductivity of objects where different objects or liquid flow have different conductivity. Electrical resistance tomography consists of hardware and software. For hardware, the main components that involved are electrode plate or known as probe. This method usually used in process engineering and geophysics engineering because this system can detects the differences of conductivity between solids or liquid mixing. [51]

Electrical resistance tomography method has been use in early 1920. [51]This method is used for geophysics engineering where metallic electrodes were inserted into the ground for soils analysis. Electrical resistance tomography has been used in medical field in 1970. Circular arrays of electrodes are being introduced at that era because it is low cost. This technique also applied in spectroscopic method to detect disease tissue in human body. [51] In electrical resistance tomography, the probe is directly inserted into the substances that want to be measured. The probe must be injected with alternating current flow. Unfortunately, this is not suitable for certain objects especially for human body. For example, this electrode plate cannot have more than 5mA peak to peak current flow for medical user. It is because our sub epidermal tissues are relatively good electrical conductors. [51]

Electrical resistance tomography is widely used in geophysics sector starting from 1989. It is because this method has capability to measure the distribution of electrical resistivity at wide area. [52] In geophysics, the electrode metals were buried in the ground to measured region of interest. The advantages of using this method are; have high sensitivity to porosity and pore connectivity. [52] Besides that, it is low coast, portable, easy to implement and high sensitivity.

2.2 The Principal of Electrical Resistance Tomography System

The main principal of electric resistance tomography is based on; different liquid or solid medium, have different electrical properties. [61] The basics construction of electrical resistance tomography consists of four number of electrode plates. The first two numbers of electrodes will be injected with current flow while another two electrodes are used to measure the resulting electrode potential. [52] Nowadays, most of the development for electrical resistance tomography consist 16 numbers of electrical resistance elements sensing ring that oriented axially to the vessel or pipeline diameter. Figure 1 show the image of vessels that applied 4 x 16 electrical resistance elements on its walls. [56] This electrical resistance method is applied on stirred mixing vessels model that used in process industry. This method can apply in stirred mixing process that deals with gas- liquid mixing and solid –liquid mixing. This system can detect the existence of transparent or opaque liquid too. [56]

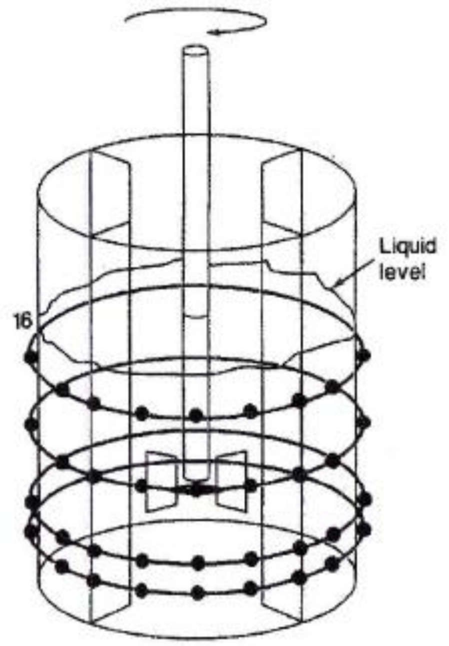

Figure 1: Stirred mixing vessels with electrical resistance tomography system.

There are multiple electrodes that use in electrical resistance tomography system and this sensor is arranged around or within the region of interest. [80] The electrodes must be inserting into the objects that want to measure because it use for exciting current and detecting conductivity. The resistance distribution information will be obtained by measuring the voltage differences between the electrodes probes. This method is non intrusive method but invasively with its boundary. [53] The main objective of this method is to gain an image reconstruction of spatial conductivity distribution that produces by the current injected into each electrode that attached to the region of interest. [55] Besides that, this system has the ability to measured velocity in both axial and radial direction by using dual electrical resistance tomography. [79]

From the explanation above, the differences of electrical resistance tomography system compare to other tomography systems are, this system must be continuous electrical contact with the electrolyte and the sensors must be more conductive compare to the electrolyte to obtain reliable measurements. [75].

2.3 Basic Construction of Electrical Resistance Tomography

Electrical resistance tomography consists of three main parts where there are hardware, data acquisition system and software. The sensors that used in electrical resistance tomography are known as electrode. This electrode can be fabricated from stainless steel, silver, gold or platinum. The most important is the probe must be a good electrical conductor. [51] High numbers of electrode can increased the image resolution.

The size of electrodes is very important to consider. The width of electrode should small enough to reduce the contact resistance between the electrode and the measured medium. The height of electrode is an important part because it can give high accuracy of measurement on the distribution of it sensitivity field. [61] Some researchers have developed a micro electrical resistance tomography electrode. The size of electrode can reach less than 1mm. This size of electrode is used for certain type of process industries that deal with flowing particulates. [97]

The type of vessel and pipeline also need to be considered. There are two type of vessel or pipeline, acrylic and metallic vessel or pipeline. For acrylic pipeline which is an insulator, the metal electrode can directly attach to the wall of pipeline. But for metal vessel or pipeline, insulating spacer need to be used to separate the metal electrode and wall of vessel or pipeline. Figure 2 show the configuration of these two methods. [51]

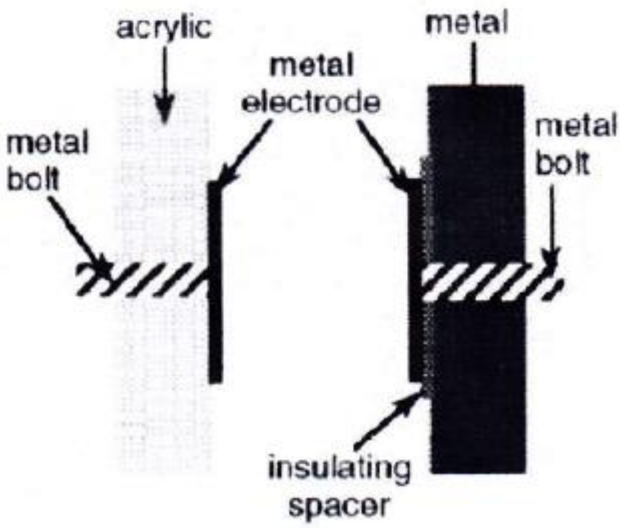

Figure 2: Electrode fabrication [51]

The insulator should be wide enough to cover all the surface area of the vessel or pipeline to produce a non conducting area. If this metal vessel or pipeline is exposed with metal electrode, the image reconstruction will include the wall or the boundary of pipeline or vessel. [51]

In electrical resistance tomography, the components that involved are; transmitter which is the electrode plate that receive current injection, receiver which is the electrode plate that measured the resulting electrode potentials, and multiplexer that used to connect electrodes from transmitter to receiver. [52] Multiplexer that used in electrical resistance tomography system should be low on resistance, fast switching speed, and low power consumption. [51]

Usually, electrical resistance tomography system is applied at the vertical pipeline. It is because, for vertical pipeline, the separation of gas and water does not exist. So, this tomography method can work accurately to measure the conductivity of liquid mixture. But for horizontal pipeline, the separation of gas and liquid will exist. Some horizontal pipeline such as stratified flow, wave flow, slug flow and plug flow, separation of gas and liquid will happen. When this happen, electrical resistance tomography cannot worked smoothly because gas will touched the wall of pipeline and will not give any reading to the electrode. [72] To overcome these problems, new instrument known as liquid level detection is applied with electrical resistance tomography to enhance the ability and accuracy of image reconstruction. [72]

The properties of current inject also play the main role in electrical resistance tomography method. There are various types of current injection methods such as adjacent, opposites, multi-reference, and conducting boundaries method. [53] The amplitude of injecting current should be base on the specification of process involved. For an example, low frequency of current flow needed for soils analysis because it is slow changing process. [53] Some sources said that high current flow and low voltage measurement is required to give high resolution of image reconstruction. [55] Some researchers state that, high excitation of current is needed for large vessels because wall effect will decrease when the size of vessels increased. [71]

The basic principal of electrical resistance tomography is based on the value of current and voltage relationship. [8] Once the current is injected into the probe, the probe will become an electrode. This electrode must touching the objects that want to measure and this will cause a current flow on the object body. The voltage different that occurred between the injected probe and non injected probe will provide the resistivity or conductivity value of object measured.[70] From this value, the signals will send to the multiplexer and amplifier to give good output signals for image reconstruction. Finally, the details in image reconstruction will tell the conductivity region and non conductivity region for image analysis. As a conclusion, electrical resistance tomography concept is based on the estimation of electrical conductivity distribution in miscible mixture that produces by current and voltage relationship. [58] This method is a simple method, robust system and can measured wide range of applications including interrogation of mixing process. [68]

In electrical resistance tomography system, usually it used alternating current so demodulation circuit and low pass filter are needed in data acquisition system. [100] High performance of data acquisition system is required to obtain accurate information. A good data acquisition system can eliminate the influence from transient time of alternating current coupling interface, signal demodulation and data transmission. [61] This technique has the ability to capture data almost 100 frame per second. This shows that this system can be used to monitor rapid transient behaviour during mixing process. [65]

Electrical resistance tomography produces cross sectional image reconstruction that based on conductivity or resistivity of objects. This conductivity or resistivity map can be analyzed using inverse problems. The suitable algorithm for electrical resistance tomography is linear back projection which is the simplest algorithm. [82]

There are two different methods that can be used to produce image reconstruction from electrical resistance tomography method. Inverse problem is one of the methods where the sensitivity map is address using quadratic model that approximates the operator mapping the unknown parameter into boundary data. [90] Another method is known as forward problem method. In forward problem method, finite element method is used to provide image reconstruction. This method is validating the result by comparing two and three dimensional simulations result with experimental results obtained in a homogenous medium. [89] This experimental and simulations result will be analyze to check or determine the sensitivity of electrical resistance tomography sensors. [89]

There are four step can be taken to produce high quality of image reconstructions; first, by collecting data over long period especially for substances that are in equilibrium or in slow dynamics, second in collecting data using different current injections and voltage measurements, third by reconstruct image using different algorithm and fourth by applied artificial intelligent approach. [83]

2.4 Applications of Electrical Resistance Tomography

2.4.1 Electrical Resistance Tomography in Process Industry

Electrical resistance tomography is important in process industry to measure the concentration and velocity distribution of miscible liquid mixing. [57] Miscible is a process forming homogenous liquid mixture. By using this method, it can detect the changes in conductivity and resistivity of liquid mixture. Due to the large equipment of tanks, vessels and pipeline in mixing industry, electrical resistance tomography becomes an important instrument for monitoring purpose. Besides that, characteristic of electrical resistance tomography such as non intrusive instrument, high temporal resolution and low cost have attract today's industry to apply it in their plant. [58]Electrical resistance tomography also suitable to use for monitoring opaque liquid or opaque mixture compared to optical tomography method because its works based on the changes of conductivity of object. But, for optical tomography, the opacity or transparency of substance is important. [93] Electrical resistance tomography is suitable for online monitoring process measurement. This on line monitoring not only important for flow pattern and flow rate analysis, but it is also important for safety operation. [59]

i. Electrical resistance tomography for single phase and multiphase process

Electrical resistance tomography can apply in single phase or multi phase process measurement. As we know, multiphase monitoring process is complex because they need to monitor more than one reaction of substances. In previous multiphase process industries, they used single phase measurement system such as differential pressure, vortex, thermal anemometers and many more. [59] Separators also needed to separate the mixture of substances before can be measured using this single phase instrument. Surely, high cost and complex system is required. To solve this problem, researchers start to develop electrical resistance tomography system for multiphase process industry. This method also can provide two or three dimensional image reconstruction for multiphase flow analysis. Some industry use neural network approach to reconstruct accurate and high resolution of multiphase image. [59].

The combination of single phase system and electrical resistance tomography system also being introduce. This new invention is use for air-water flow measurement system. This new development of flow measurement rate is the combination of venturi meter and electrical resistance tomography method. Venturi meter is selected because it has the lowest pressure lost compared to other differential pressures flow meter while electrical resistance tomography is use because it can enhanced the performance of differential pressure flow meter. [60] Besides that, electrical resistance tomography method very suitable for air-water flow measurement because water is a good conductor. [60] Sometimes, this tomography system also applied in hydro cyclone operation for industrial monitoring and to enhance the capability of system to produce high quality of output. [74]

This method also has been used in chemical engineering that deals with gas-liquid mixing process. In chemical engineering, the combination of different type of gases such as hydrogen, chlorine and oxygen usually contacted with hydrocarbon liquids. Besides that, the mixing of air in bioreactor need to be monitor because this reaction can cause the existence of micro-organism dissolved in the oxygen.[69] So, electrical resistance tomography is use to discriminate and to avoid this problems occurred. The capability of electrical resistance tomography to detect the conductivity differences in different elements of gases and liquid give the good effects for chemical engineering industry.

Electrical resistance tomography for leakage

ii. detection

Electrical resistance tomography also being used to detect leaks from buried pipes. [62] This method has capability to detect leaks because small changes of resistivity or conductivity can give a voltage differences. Some research use voltage difference from non conductive leaking as voltage reference and compare the result that obtain from the on line monitoring leak detection process. [62]

iii. Electrical resistance tomography for slurry mixing

Electrical resistance tomography for slurry mixing models also developed in today's industry. This method is being use because electrical resistance tomography can detect opaque objects or solids distributions. [95] Slurry mixing models usually measure the solid-liquid mixing process and it have two main criteria that need to be considered. The two criteria are; the minimum speed for impeller must be recognize to suspend all the particles from the base of vessel and the mixer must be achieve the uniformity of the distribution of particles involved. [65] Besides that, other factors that can affecting on solid liquid suspension are; physical properties of liquid such as density and viscosity and physical properties of solids such as density, particles sizes, wetting characteristic, tendency to entrap air and hardness also need to be considered to make sure the output product archived its specification. [67] So, to monitor this entire requirement, electrical resistance tomography is being used. This method can provide two or three dimensional image of slurry mixing process. This image reconstruction is produce depends on the different conductivity for each different substance. [65] From the image reconstruction, operator can indicate the part in mixer that has high concentration of particles or solids for monitoring process. To achieve the high resolution of image reconstruction of solids distributions, the large number of electrode is needed. [95]

iv. Electrical resistance tomography for bubble column

Electrical resistance tomography also widely used in bubble column. Industries that deal with reaction such as oxidation, chlorination, polymerisation, and hydrogenation using bubble column. [75] This tomography system plays an important instrument to apply at bubble column for monitoring process in chemical industry. Bubble behaviour is very important to investigate because bubbles can affect the specific gas-liquid interfacial area, residents' time distributions, and transfer rates and reactions rates in chemical process. [76] Bubbles also can divide into two types, small bubbles and large bubbles based on the rise velocity of the bubbles and the different dynamics characteristic when the bubbles rise up in the column. [76] This tomography methods is the most suitable method to measure and visualise the regions of different density with high gas fraction, bubbles opacity and the relative fragility of the systems. [82] Electrical resistance tomography is the most suitable system to measure the behaviour of bubbles because it is a fast imaging technique but with low spatial resolutions which estimate the gas hold up based on the boundary voltage measurements. [76] Detection for swirling bubbles air in water flow also can be conducted by electrical resistance tomography system. This tomography system can produce three dimensional image of swirling bubbles air-water flow using based correlated pixels method. [77] Actually, optical tomography method also used for bubbles detection. This method can produce good image reconstruction for bubbles detection but it takes long data acquisition and only suitable for highly stables bubbles systems. [82]

v. Electrical resistance tomography for jet mixer

Electrical resistance tomography also used for coaxial jet mixing. Coaxial jet and side entry mixers are widely used in industries that deal with process of polymerizations, neutralization, and perceptions. The characteristics of jet mixer are, it's operate in continuous or semi- batch mode and have short contacts between jet mixers and fluids. [78] This system tomography is very important to monitor jet mixing via the addition of a conductivity tracer through coaxial and side entry jets. This tomography method is non intrusive and it is useful to monitor on line process and can reconstruct a three dimensional images. [78]

vi. Electrical resistance tomography for food processing

This method also uses in food processing industry such as yogurt, milk, sauce and ketchup industries. The image of concentration for each mixing process is required for analysis the quality and the quantity of products. Previously, food processing industries used sound Doppler and laser Doppler to measure the velocity of food flow in pipeline. Unfortunately, this method only can give velocity measurement. But, by using electrical resistance tomography system, it can give accurate calculation where the cross sectional image of flow measured can be seen and can be analysis for its concentration details. [79] At the same time, the quality product also can be monitor continuously.

In food processing industries, control and monitoring of temperature, pressure, flow, concentration, compositions, hygiene, taste and smell are compulsory. Especially in milk industry, to control the quality of milk is very complicated because milk easily can attack by bacteria. Besides that, milk that full in big tanks easily separated in two phases, liquid and cream that cause by gravity forces. [80] So, electrical resistance tomography is very important instrument that can be use to visualize the cross sectional image of milk in tanks for monitoring process.

vii. Electrical resistance tomography for particulate processing

Particulate processing is one of the important fields in today's industries. Industries that involve in particulates processing are mineral industry, pharmaceutical, nuclear and aerospace. For an example, this tomography system has been used in reactive crystallisation sector. This method is used to monitor the reaction of barium sulphate from earlier stage until the end stage. In this field, process monitoring that involved such as formation of bed deposits, particles becomes stationary, and flow pattern are very important. By using electrical resistance tomography methods, the image reconstruction that show the formation and solids or particles distributions of this can be visualize with different colour to show different changes of concentration and conductivity. [81]

viii. Electrical resistance tomography for flow model chip digester

Flow model chip digester is the process that digests the chemical pulp using high pressured reactor and this process produce craft pulp. [88] This process involves liquor called sodium hydroxide and sodium sulphide which are active chemicals. The high pressure, and control temperature are needed to produce the right specification of craft pulp. So, electrical resistance tomography is use because operator can monitor the chemical reaction and ratio through image produces. [88]Besides that, by using electrical resistance tomography, the digester performance can be improved the uniformity of pulp produced during batch operations. This method also help in increased the production, improved process stability and controllability, lower bleaching chemical usage. [94]

2.4.2 Electrical Resistance Tomography in Construction Sector

Electrical resistance tomography also widely use in construction sector. Concrete usually consists of horizontal steel bar, vertical steel bar, plastic plates and polyurethane block. All this components have different value of conductivity and resistivity. Surely, this system can sense the deterioration process that happen to concrete building. [63] This knowledge is very important so that quick action can be done at early stage. Electrical resistance tomography system also can give information about the degree of cracking in the reinforced concrete, the distribution of chlorides in the matrix, the humidity gradient in concrete, and the state of corrosion. [63]

Electrical resistance tomography has been used in archaeology field. This technique can detects and characterizes layers of concrete or soils by extracted resistivity contrast between different layers using electrical current. [64] This technique is very useful for geologist because it is low cost method, portable and easy to implement.

2.4.3 Electrical Resistance Tomography in Geophysics

This method also used in geophysics field because it has the potential to provide underground process image that affects the electrical properties of soils and pore fluids. Usually, the results obtained will be combined with other geophysical, hydrological, or geochemical technology for further analysis. [66] This technique can produce a two dimensional or three dimensional image reconstruction of subsurface resistivity distribution and this information are very important for characterizing the heterogeneous of subsurface. From this soil analysis, researcher has made a conclusion that the resistivity of soil medium will decrease with the increasing of moisture contents and type of soils. [66]

Geophysics analysis is being developed day by day because of the environment issues such as climate changes, water management and soil pollution. According to that problems, many non destructive analysis were carry on such as ground penetrating radar, isotopes, X-ray imaging, and magnetic resonance imaging has been used for observing roots and their function at macro and micro scales. But certain methods have their limitations. [91]

In geophysics fields, the study of coupled thermal- hydrologic-mechanical processes in rocks also becomes an important part. This study is important to determine the movement of moisture, rock mass deformation, and to analyze the temperature field in the rock. But this process is very slow process and it is impossible to directly measure the performance except for very small portion of natural interaction.[92] One method that used to monitor this process is electrical resistance tomography because this method has high spatial resolution and very sensitive to conductivity changes. [92]

2.4.4 Electrical Resistance Tomography for Monitoring of a Radioactive Waste Separation Process

Rotating separator is use to separate the soluble fission product which are uranyl nitrate and plutonium nitrate and insoluble fission which are technetium-99, strontium-90, ruthenium-106, caesium-137, and cerium-144. This rotating separator is use in radioactive waste separation process system. This process is known as nuclear reprocessing. [84] This electrical resistance tomography is use to monitor the separation process in rotating cylindrical separator.

2.4.5 Electrical Resistance Tomography for Monitoring of Carbon Dioxide Sequestration Process

Electrical resistance tomography system is very important to monitor carbon dioxide sequestration process to check the performance of the reservoir system, access leaks and flow paths, understand the geophysical and geochemical interaction with carbon dioxide and geologic minerals and fluid. Actually, electrical resistance tomography system can give useful information related to the behaviours of carbon dioxide from image visualisation. This method can help control room operator to monitor this process continuously. The image reconstructions that produce by this method are based on the changes of resistivity caused by carbon dioxide injection and migration. [85]

2.4.6 Electrical Resistance Tomography in Medical

Electrical resistance tomography has been used for imaging depolarization in the brain. But, the changes of resistivity are very small and hard to detect. [86] In medical field, the current flow should be less than 5mA so this become one of the possibility that the changes conductivity at neuronal depolarization hard to measure. To solve this problem, some researchers use another approach that used direct current but the result still not satisfied because of the noise effect. [86]

This tomography system also applies for pharmaceutical process. [87] Pharmaceutical process industry processing drugs for medical used. This type of sensors is used as screening tools to monitor the chemical reaction with huge number of acids and organic solvents with variations of temperature involve producing drugs or medicine. [87]

2.5 Conclusions

Electrical resistance tomography is widely used in medical diagnosis, two-phase flow measurement system, chemical engineering and geophysical prospecting. [98] This system is come from the traditional electrical geophysical profiling where four numbers of electrodes are inserting into ground to determine the spatial distribution of electrical resistivity within the region of interest. [99] This tomography method has it speciality where it can detect the changes of conductivity or resistivity of certain elements although it is opaque or transparent liquid or solids. Besides that, this method has advantages where it is low cost, fast data captured and safety. [98] The construction of this system is depends on the size of pipeline or vessels that being used. [97] This method is portable and easy to implement. For image reconstruction, inversed method usually used based on finite element modelling approach. [99]To get high quality and rich information of image reconstructions, different value of current and frequency is suggested. [96]Besides that, more electrodes that being used is another approach to give high quality of image output.

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CHAPTER 3

Electrical Impedance Tomography (EIT)

3.1 Introduction

Electrical impedance tomography method is one of tomography method that has been used widely in medical field. This tomography method can be classified as electromagnetic tomography modalities. In electromagnetic tomography there are consists of electrical capacitance tomography, electrical impedance tomography and magnetic induction tomography. [146]This method can produced a cross sectional image of conductive region of interest. This system is known as soft field method. [139]The basic structure or concept of impedance tomography methods is same with electrical resistance tomography method, where it used a pair of electrodes to measure the region of interest. But the way it measure a little bit different where electrical resistance method measure the resistivity of object while electrical impedance tomography measure the impedance. Impedance is a complex ratio of the voltage and current in an alternating current circuit. [107] Impedance consist of two part; real and imaginary part. The differentiation between electrical impedance tomography and electrical resistance tomography also come from the calculation and algorithm. [139]

Electrical impedance tomography is use in medical imaging, non-destructive testing, geophysical prospection and industrial process monitoring. [149] But, this tomography method is widely use in medical field because it is not requiring the exposure of ionizing radiation.[101] This system also portable, low cost, but has low spatial resolution.[107] Besides that, this system is suitable for studying the physiological process which modify the electrical conductivity of body. This system can produce an image of respiratory and gastric activity base on the conductivity distribution by the movements of liquids or gasses. [124]This method widely uses to monitor lung problems, heart function and blood flow, internal bleeding, screening breast cancer and many more. [101]This system also a validate system for imaging gastric function, pulmonary ventilation, brain function, pelvic congestion, hyperthermia and other gastrointestinal function. [107] Electrical impedance tomography firstly used to monitor respiratory function in 1983. [102]Previously, they use pressure volume curves and respiratory system compliance but these systems not capable to produce data of lung process at regional basis. [102]Electrical impedance tomography system is very good to use in medical fields because it has high sensitivity to the movement of bloods and other fluids in our body and it is suitable to apply for real time imaging process. [109]In medical applications, electrical impedance tomography has two types of different current applied. First, it called as Applied Potential Tomography (APT) where electrical currents are applied to the body using a pair of adjacent electrodes. Second method is known as Applied Current Method (ACT) where the electrical currents are applied to all the electrodes and voltage different between the electrodes are measured. [101]

For image reconstructions algorithm, electrical impedance tomography method produce a little bit complex compare to other method such as CT image and X-Ray computed tomography because both applications only let a direct beam of radiation go through the region of interest and the scattering of energy can neglect. But, for electrical impedance tomography, scattering energy need to be consider because it work based on the distribution of electrical currents. It is a non linear method of measurement. [102]For this tomography method, the image reconstruction is produce by determining the inverse problems. [125]The speciality of this method is, it is a high speed measurement system and it can capture repeated changes of electrical properties that occurred at the region of interest. [2]This method also can produce real time images and can captured video stream of regional ventilation. [104]

Today's application using electrical impedance tomography can produce two dimensional images and three dimensional images.[106] For two dimensional images, the data gathered is base on the sensors or electrodes that position around the body of entire object measured. [106]This two dimensional image can be produce using non iterative reconstruction algorithm. [126] But, for three dimensional images, the image reconstruction required the entire surface of the object volume data. [106] Three dimensional image procedure also face with some difficulties such as high demand for computational process, and quite sensitive to numerical or data error and to reduce some of these problems, researcher develop a non iterative procedures. [127]

In any types of tomography methods, these systems faced with the same problem which is low quality of image reconstruction. The main reason of this problem usually due to the hardware construction which is not shielded firmly and this can cause noise. Besides that, low quality image also come from the approximation of potential field model in the sensitivity matrix calculation. [106] to give high precision of image reconstruction using electrical impedance tomography method; many new development of this system is introduced. Many different strategies are applied such as additional electrodes, multiple electrodes current injection and multiple frequencies applied. [107]Sometimes, it's hard to measure the accuracy of image because different natures of application have different conductivity and permittivity. So as a conclusion, to produce high quality of image, it depends on the application is used for. From that stage of knowledge, the development of electrical impedance tomography can be made according to the requirement of applications to produce high quality of image reconstruction. [107]

Electrical impedance tomography faces with nonlinearity problems. Researcher in today's are nonstop developing new algorithm to solved this problem. For an example, they introduce sparsity concept for image reconstruction that can produce accurate and sharp image. This reconstruction method gives very close conductivity location with the true value. [119]Some other researcher introduced an application of induced current. [108]This method has been introduced since 1990 as a new invention for conductivity imaging of human tissues. [108]In this method, different shapes of coil are used to generate different primary magnetic fields. As we know, induced current is proportional to the rate of the changes of flux in a loop of wire. From their research, they found that induce current can produce more independent measurements compared to injected currents. But for injecting currents method, number of electrodes should be increased to produce more independent measurement results. [108]Another perspective shows that the large number of electrodes can cause high loading for computational time for image reconstruction. [112]Besides that, the best selecting of conductivity distribution can contribute for the image reconstruction enhancement. [123]

3.2 Basic Construction of Electrical Impedance Methods

The basics concept for electrical impedance tomography is same with electrical resistance tomography. This method required a minimum two numbers of electrodes plates. Both electrodes must be inserted in the object that we want to construct it cross sectional images. One of the electrodes will act as transmitter and another one act as transmitter. While the current flow through the electrodes, the changes of conductivity and permittivity can be measure easily.

The reason why this method widely uses in medical fields is because; it has capability to differentiate various types of tissues in our body. As we know, different tissues contribute different reading of conductivity and permittivity. Besides that, the information of the high value or low value of conductivity can be seen by image reconstruction. By analyse this image, researchers will get many information of region lung. [103]This method is very important in medical field to monitor collapsed or fluid filled lung, blood flow, and cardiac function. [103]For the lung monitoring process, the distribution of electrical conductivity is based on the alveolar volume stretches. [135]

Electrical impedance tomography system has two main part; hardware and software. For hardware, it consists of many numbers of electrodes that act as transmitter and receivers. This transmitter and receiver can be known as active electrode and passive electrode where active electrode is injected by the current and passive electrode for voltage measurement. [127]For electrode, the low value of contact impedance should be select to gain an accurate data measurement. Normally, 16 numbers of electrode being use because the right numbers of electrodes also can reduce the measurement error due to the contact impedance. [130]All the outputs voltage that given by electrodes will be combined using multiplexer and usually this multiplexer can acquired more than hundreds measurements at one seconds. [140] the receiver will connect with other circuit that can amplify the output reading. After that, this amplified output signal will be send to the data acquisition system. This data acquisition system has two main parts which is timing generator and microcontroller. [109] This timing generator is controlled by microcontroller to produce all the timing and clock signal required for synchronizing the data with computer software. [109]Finally, computer software will generate the output as a sensitivity matrix that describes the relationship between conductivity changes and the boundary voltages. [141] Figure 1 show the basic construction of electrical impedance tomography method measuring the head phantom. [145]

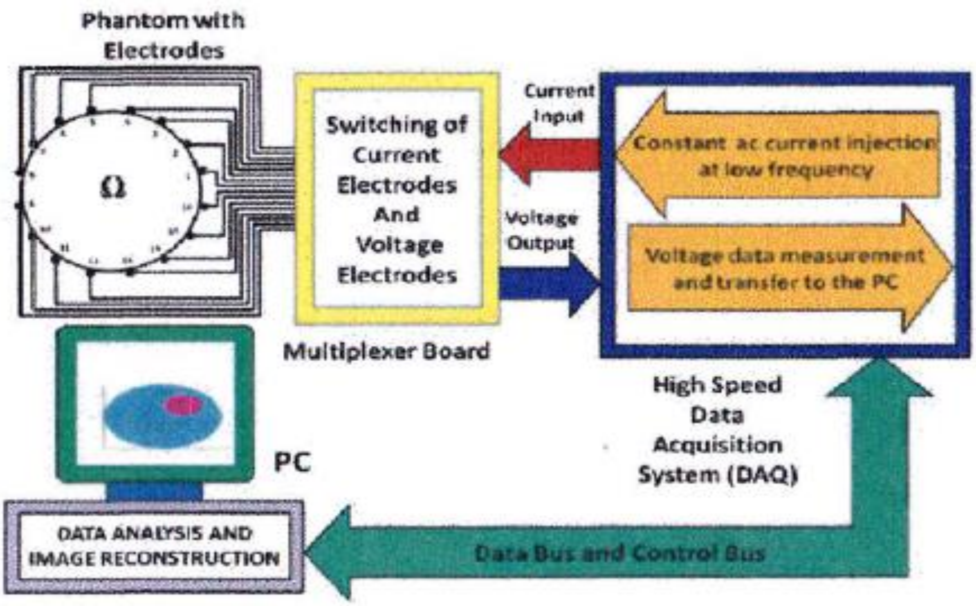

Figure 1: Basic construction for electrical impedance tomography

3.3 Image reconstruction

Electrical impedance tomography system is important in medical field and because of that, the quality of image reconstruction that produce by this system should good enough for analysis. This tomography method has its weaknesses due to low spatial resolution and unclear boundary imaging. Researchers have developed many different algorithms to solve this problem. There are two reconstruction algorithms methods that need to apply; forward problem and inverse problem. For forward problem, it help electrical impedance tomography problem to calculate boundary voltages with given electrical conductivity distribution. While for inverse problem, it takes voltage measurement at the boundary to estimates the conductivity distribution. [148]It has two parts, dynamic and static inverse problem. For dynamic inverse problem, it classified as linear non-iterative while for static inverse problem is iterative algorithms. Most of the iterative numerical algorithm has high performance in imaging high quality and accurate image. [140]

This image reconstruction of the conductivity is a nonlinear inverse boundary value problem. Nonlinear boundary value problem is unstable and has modelling errors. Modelling errors usually cause by truncation of the computational domain and unknown boundary data. [147]Many ideas have been used to increase the quality of image reconstruction by using electrical impedance tomography system. For an example, the number of electrodes must be increased to give high spatial resolution. Multiple current sources also must be match to give a good performance of system. Amplifier that been use in this system must be isolated from receiver by a transformer because this arrangement can act as high pass filter to reduce electrophysiological signals affect the accuracy of the measurements. [109]Sometimes, the low accuracy of image reconstruction is because of the noise that due to spatial variations in applied currents or voltages. To reduce this noise, it is suggested to apply currents and measured voltages rather than applies voltages and measured currents. [105]

Another problem due to the image reconstruction is the boundary problems. Besides that, this boundary problem also occurred clearly when it use for monitoring chest changes breathing. [143]Some researchers have come out with new idea which is called as model shape match. Many experiments are carrying out to get the average shape of certain organs. From the image result it can be use for comparison for medical analysis. This procedure actually complicated and can cause mismatch problems. It is because different patient have different shape of organ. But, by using different reconstruction algorithm, this mismatch problem can give a small error. [133] Finite element methods also use in electrical impedance tomography methods for image reconstruction. This finite element method is a method that has been use to reconstruct an image by solving it differential equation with different image modalities. [141]

3.4 Applications of Electrical Impedance Tomography Methods

Electrical impedance tomography mostly used in medical field. But, this method also contributes for geophysics and environmental science for locating underground mineral deposits and detecting leaks underground pipe. It also can be use for detecting corrosion, and small defect such as cracks. [103]This system also can be applied for the process industries application. For an example, this system is capable to measure the impedance distribution insides a small vessel by placing the electrodes around the vessels. [122]This method is very useful to apply in industries for real time process monitoring.

This method is use in medical because it has the capability to detect and identify cells based on the sizes, orientation, and thickness of membranes. In our body, the fluids contribute as conductive region while cells contribute as permittivity regions. [103]This conductivity and permittivity value is totally give different value base on different tissues and organs. [128] But, safety standards must be full fill by this system because it deals with human life. [107]

There are another reasons why electrical impedance tomography method is really needed in today's medical field. The existing instrumentation such as magnetic resonance imaging (MRI) and computerized tomography (CT) have their limitations. For magnetic resonance imaging, it gives high spatial resolution of image but this instrument cannot detect the present of cancer tissues at early stage. [131]Besides that, this instrument is not suggested to use rapidly because patient can expose to the radiation. Another method to detect cancer is by using ultrasound devices. This ultrasound device also has limitation where this system only can detect lump which is solid or filled with fluid. [131] Electrical impedance tomography has many advantages such as non-invasive, low cost, and no ionizing radiation but this system also has the disadvantage where this system is easily can detect slightly external voltage or current interruption and this will cause huge effect in internal conductivity value. [132] Another advantages of this system is ; it is a long term measurement system where this system can monitor patient for real time monitoring process for a long period without give any side effect to the patients. [133]

3.4.1 Electrical Impedance Tomography for Medical Field.

i. New improvement for electrical impedance tomography by using Nano-particle Sensitizers

Bioelectric impedance measurement is a safe way to determine the electrical properties of tissues inside human body. [110]This method measures the changes in electrical properties that occur in tissues body. This application is important to detect early stage of cancer. [110]To increase the ability of electrical impedance tomography method to detect the changes of cells or tissues conductivity, nano-particle enhanced method is introduced. [110]The basic concept of this tomography method is by measuring the potential on body surface by injecting small amount of current into human body. Sensitizers are introduced in this medical application to enhance the image produce by this tomography method. The types of sanitizers are ultra pure water, normal saline, and gold particle. [110]For ultra pure water, it will help increased the impedance of tissues due to its high conductivity. Normal saline also will increase the conductivity of tissues. This method will help doctor to differentiate the normal and cancerous tissues. [110]By using this sanitizers, tumours can be detected at early stages. [110]Beside that, nano-particles is suitable to use because of it miniature size and can reduce harm from side effect. These sensitizers help to improve the accuracy and high quality of image reconstruction.

ii. Electrical impedance tomography for imaging tissues cells

Living tissues cells have a conducting cytoplasm and covered by a thin layer of insulating cells membrane. When these cells exposed with an electric field, this cells will behave as an insulating objects. This result will help electrical impedance tomography system to measure electrical properties in the cells. The growth, differentiation and the effect of drugs can be monitored using this tomography method. [145]

Electrical impedance tomography method can produce an image reconstruction that map the electrical impedance distribution inside human tissues. Changes in membranes resistance can be enhance by using fluorescent marker (sensitizers), current voltage measurement and patch clamps. [111]This method is applied by surrounding the body or organ with electrodes that have injection of currents. This method is very useful for detection cancer at early stages. It is because this method is safe from any ionizing radiation that can give some bad affect to our body. [112]One of the applications of electrical impedance tomography is use for breast cancer detection. This system becomes one of the alternative methods to diagnosis and imaging the breast cancer tissues. [127]Although it is low spatial resolution, but it is low cost, portable and not produce any hazardous radiation to patients. [127]

iii. Electrical impedance tomography for monitoring lung air and liquid volumes

Previously, pulmonary mechanics parameter is use to measure the flow and pressure at mouth and oesophagus, while X-Ray is use to measure the fluid movements in lungs. However both method has their limitation and disadvantages. [113] Lung air monitoring usually need to be monitor for continuously, but X-Ray tomography use ionizing radiation that is not good for continuous exposure of patients. [113]By using electrical impedance tomography system, it can provide valuable information regarding to the state of aeration and ventilation within the lung. [114] Low constant value of alternating current is applied to the electrode as low as 5 ma. Besides that, low pass filter need to be used to eliminate the cardiac oscillation. [120]This tomography system work based on the changes of the conductivity sense. For an example, when air is filling in the lung, the impedance will change due to breathing process. Fortunately, the large changes of impedance occurred at thorax where functioning lung tissues present. There are two types of ventilation modes. First it is known as spontaneous breathing and mechanical ventilation. The data obtain is base on the changes of lung impedance during spontaneous or ventilator generated breathing. Lung injury also can detect because this part usually consist of low impedance. [115]This tomography method is highly recommended for the use of lung monitoring process because it is non invasive method, free from radiation, easy to implement and portable. It also can monitor real time process system. Figure 2 show the image reconstruction related to the inhalation and exhalation cycle that produce by online monitoring of electrical impedance tomography system. [150]

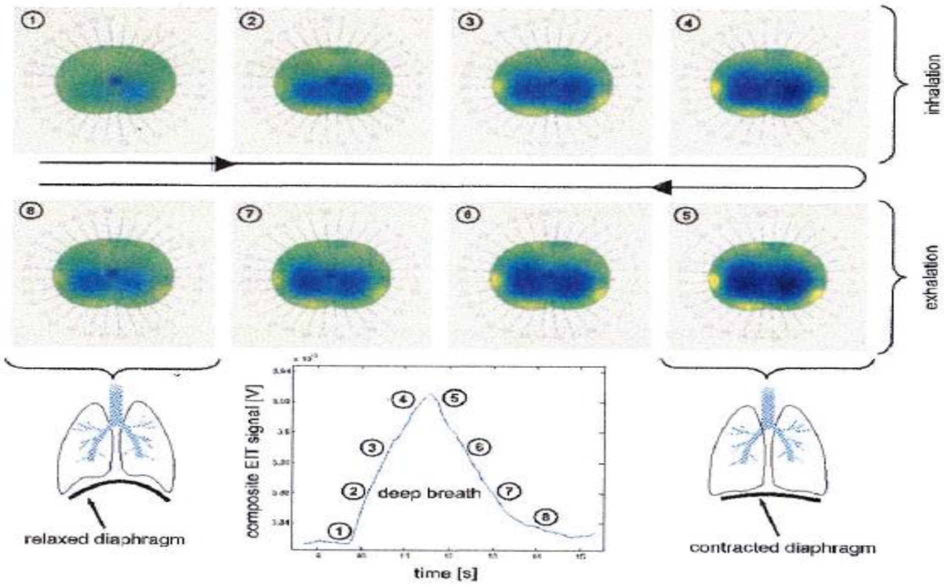

Figure 2: Image reconstruction of thorax region during inhalation and exhalation cycle.

Electrical impedance tomography method also can be used to monitor and diagnosis for pulmonary embolism. Pulmonary embolism happen when there are a blockage occurred at pulmonary artery or its branches by emboli travels through the bloodstream. The image of this problem can be capture base on the impedance changes due to the flow of blood stream. Computed tomography scan is not suggested to use for critical condition patient because it expose with radiation that can cause harm to the patients. [116] Figure 3 shows how the electrode is place around human chest for monitoring lung air and liquid volume. [101]

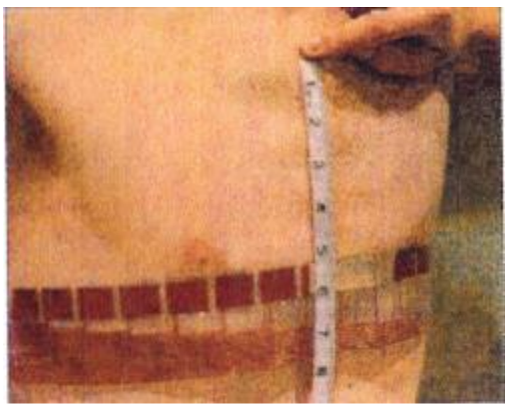

Figure 3: A stripe of electrode plate is place around human chest. [101]

Other types of sickness that related with our breathing process are known as cystic fibrosis. This is the chronic disease that affects the lungs and the digestive system. This can cause small airways and reduce the flow of air. By using electrical impedance tomography system, this problem can be diagnosis at early stage. Previously, doctors are use spirometry and body plethysmography. But all these instruments have limitation where they cannot measure ventilation distribution. [134]

In the development of this tomography method for lung monitoring, a group of researchers from China has developed a new algorithm known as Global Inhomogeneity (GI) index. The main objective of this new algorithm is to quantify the tidal volume distribution within the lung for electrical impedance tomography analysis. The development of this new algorithm is base on the image reconstruction captured using electrical impedance tomography system. [136]Another approach that introduce by researchers are using neural-fuzzy modelling to increase the quality of image processing. This approaches help in estimating the relationship between lung absolute resistivity and lung volume. [138]

iii. Electrical impedance tomography for intracranial application

Haemorrhage or intracranial bleeding happened when the blood vessel within the skull leaks or ruptured and it is very dangerous. This situation can cause critical issues such as increasing the intracranial pressure. This intracranial pressure may cause limitation in blood supply. Electrical resistance tomography is very useful to produce a real time image for intracranial bleeding problem. From the image visualisation, it can show the different resistivity of blood and other brain tissues. [129] One of the reasons why this method is widely use in medical application is because it can use for real time monitoring purpose without spread any chemical or hazardous radiation that can worsen the patient. Because of the speciality above, this tomography method also has been use for diagnosis brain activity, bleeding and pressure. [117]From the data obtain, sensitivity map can be reconstruct based on the detail of impedance changes in brain. [117]The development of this system is very important nowadays for brain analysis. This tomography method allow medical specialist to study deeper inside the brain function in real time monitoring. [117] Figure 4 shows the system architecture for electrical impedance tomography system for brain analysis. [117]

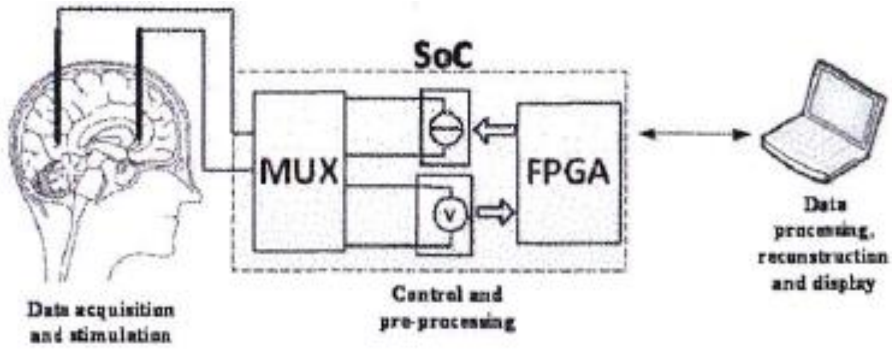

Figure 4: System Architecture for brain analysis using electrical impedance tomography method. [117]

In this case, researchers develop a micro-array of electrode as can be seen in Figure 5. This micro electrode is developing using fibreglass core and partial skull still need to open to insert this miniature electrode core. [117]

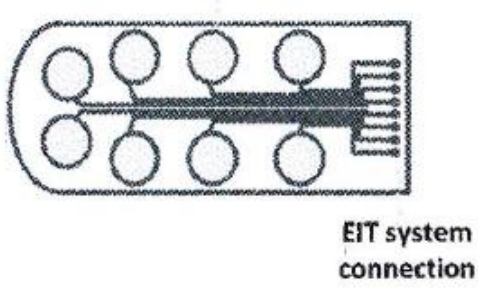

Figure 5: Micro electrode construction [117]

This tomography method also can detect brain tissues ischemia and cerebral infarction. This is due to the capability of electrical impedance tomography to detect the changes of impedance value. Another researcher found the other method to apply this system without have to access into the brain. The electrodes only need to be place around our head and tied it tightly. From their experiment, they can construct the image of swelling tissues in brain. For this case, they assume that the skull cavity is a hermetic case with constant volume; where resistivity will change proportional to the volume and tissues location changes. [117]

In medical industry, head phantoms are building by scientist for experiment purposes. These phantoms are build by scientist to make an experiments related with human tissues before they apply their system to their patients. Usually this head phantoms represent head tissues, skin, skull, cerebrospinal fluid and brain. By using this head phantom, scientist and researchers can make their studies very detail in analyzing the requirement of electrical impedances tomography to be very useful for brain analysis. [142]

iv. Electrical impedance tomography for fetus monitoring

Usually, ultrasound and cardiotocogram is used for fetus monitoring. These instruments are very important for checking fetus movement, the growth of fetus, and position of placenta.[121] This monitoring procedure is required by pregnant mother for monthly or daily monitoring of the baby and the mother itself. Electrical impedance tomography method is a new development for the use of fetus monitoring. This new development is design by researchers because they want to solve the problem that face with the previous instruments where they are bulky, expensive, time consuming and need skilled personnel to monitor. [121] For fetus monitoring, the principle of electrical impedance tomography is still the same where electrode plat have to be place around the mothers belly and low current need to be inject into the electrode. This electrode plate will measured the changes of impedance value that occurred inside the mother's belly. Image reconstruction can be produce base on the data obtain. As we know, human tissues have different conductivity and it varies from cerebrospinal fluid to bone over a large scale. [121] Figure 6 shows the system orientation on the mother's belly.

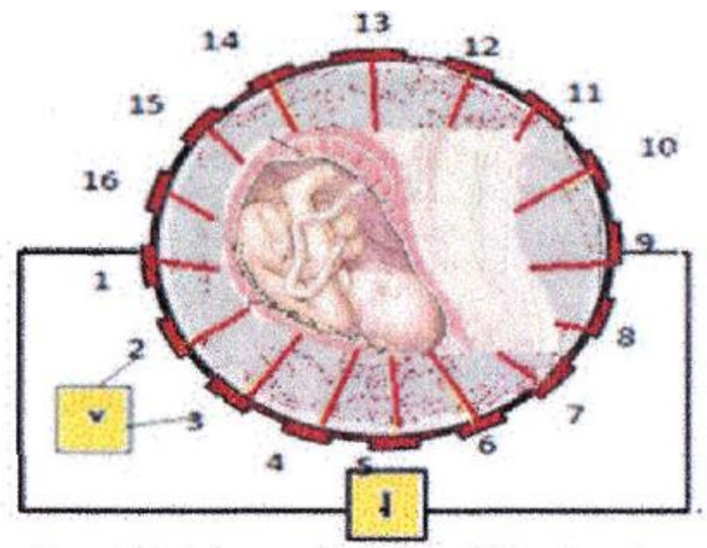

Figure 6: The orientation of electrode for fetus monitoring. [121]

v. Electrical impedance tomography system for monitoring retroperitoneal bleeding in a renal trauma patient.

Electrical impedance tomography method very useful to monitor patient that face with active retroperitoneal bleeding. If this problem is not detected at early stage, serious consequences may occurred. In medical instruments , this tomography system is the only instrument that can monitor patients continuously and can give early results about the stage of active retroperitoneal bleeding whether patient need to operate or not. [137] Figure 4 shows the way how electrical impedance tomography system is used. For this case, this system used elastic belt to ensure that electrodes plates have the good contact with the skin. [137]

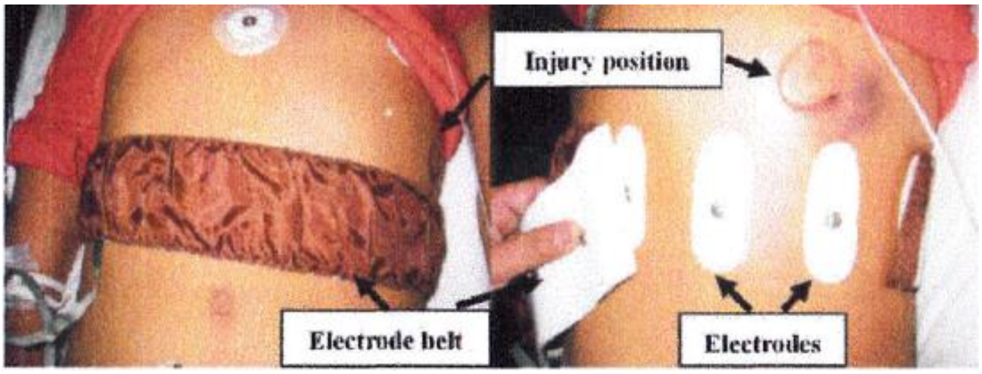

Figure 4: Electrical impedance tomography is apply for monitoring retroperitoneal bleeding

3.5 Conclusion

Electrical impedance tomography is one of the tomography methods that are suggested to use in medical fields because it is low cost, portable, bedside monitoring, and no hazardous radiation. Although this system has low spatial resolution, researchers nowadays keep on going to produce many ideas to reduce these problems. This tomography system also can enhanced it 's image reconstruction by improving the electrode model for an example by increasing the number of electrodes or by using different frequency of currents value, increase the capability of the system circuit, and studying the reconstruction method [110]. This system also should be introduce to the process industries because this system also suitable for online monitoring process.

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CHAPTER 4

Electrical Capacitance Tomography (ECT)

4.1 Introduction

Electrical capacitance tomography is one of the methods that used to captures cross sectional image of objects; solid or liquid in pipeline or vessels. This system measured the permittivity distribution of objects. This permittivity changes is nonlinear. [152]Permittivity here means the amount of electric field that is generated per unit charge in that medium. This tomography method widely used in process tomography for process diagnosis and control. [152]Usually this system involved in process tomography that deals with multiphase flows and multiphase reactors. [151]This electrical capacitance tomography method measured the changes in inter-electrode capacitance due to the change in concentration or distribution of dielectric materials in the region of interest. [157] Besides that, this system has no radiation, fast imaging speed, non –intrusive and non- invasive, withstanding high pressure and low cost. [157] Fast scanning speed is very important for online monitoring because online real time applications involving fast changing dynamics of combustions and explosion within an enclosure. [159]This tomography system also suggested using in harsh environment condition including the presence of strong external electromagnetic fields. [178]

Multiphase flow measurement system faces with many challenges especially for online monitoring because online process have high sensitivity of phase fraction that can affect the image reconstruction. Multiphase process also has different fluid properties and flow rates which difficult to predict and model. Electrical capacitance tomography is the best tomography system for multiphase analysis. [194]This system is widely applied to measure two phase process such as flames and air, gas and solids, and water and air. [152]Two phase process consists of different dielectric properties and this tomography system has capability to measured lower permittivity and higher permittivity limit. Sometimes, to measuring two phase process, they applied the combination of tomography method which is electrical capacitance tomography and differential pressure for air water bubble column. By using this collaboration, it can produce high quality of image analysis because bubbles produce different pressure level from lower to higher level. [166]

This tomography system can be considered as an instrument that use for online monitoring process industrial because it can be used continuously to measure the changes of permittivity in solids or liquids. [154]Another reason why electrical capacitance tomography system is widely used in monitoring internal behaviour of process industries is because this system high speeds, robust and non intrusive. [154]This electrical tomography method also use for visualisations of combustions flames in engine, detection of leakage from buried water pipes, and flow pattern application identifications.

The basic structure of tomography methods consist hardware and software and types of sensors make these tomography systems have different capability. Electric capacitance tomography system is considered as soft –field tomography system. For soft-field tomography system, the field of electrical properties distribution is dependent on the physical property distribution. For electrical capacitance tomography, it is known as soft-field tomography system because the electrical field lines are dependent on the permittivity distributions. [151]

Electrical capacitance tomography is under electrical tomography group. As we know, electrical tomography methods are systems that measured electrical properties such as capacitive, resistive, or inductive. But for electrical capacitance tomography systems, it already was being used since 1980. [151]This system widely applied to reconstruct two dimensional images or three dimensional image of cross sectional flow systems. This system has high capability to measured multiphase flows. [151]

4.2 Image Reconstruction

For electrical capacitance tomography method, the image reconstruction consists of inverse problem and forward problem. [170]For inverse problem, it can be classified in two main categories; non iterative and iterative method. This is due to the nonlinear relationship of measured capacitance and permittivity distribution in electrical capacitance tomography methods. For iterative methods, it is initially estimating the permittivity distribution of the process and computes the corresponding capacitances between all parameter of electrodes. [174]

4.2.1 Problems occurred in image reconstruction

There are two major problems for electrical capacitance tomography in image reconstruction. The problems that involved are discretisation and model error. To solve this problem, researchers from Poland and United Kingdom have developed approximation error model to provide statistical way to compensate these errors.[168] This approximation error model algorithm also has proved its capability to improve the image reconstruction and reduce the computational time which this approach can produce fast imaging process for online monitoring process industrial. [168]Besides that, other researchers proposed two differential potential excitation techniques to improve the non- linear forward problem in electrical capacitance tomography system algorithm. This technique is applied to produce an approximately uniform excitation field across the sensor. [170] This tomography method also faces with ill pose inverse problem which is sensitive to measurement noises and modelling error. [164]Ill posed problem happened when the number of capacitance values is smaller than the number of pixels in reconstructed image. [176]

4.2.2 Solutions for image reconstruction problems

Previously, the image reconstruction of electrical capacitance tomography is produce in two dimensional. This two dimensional is a good approximation of the actual three dimensional.[190] Regarding to the advance in today's technology, three dimensional image of cross sectional objects can be obtained by these tomography methods. [164]This three dimensional image is using by real time three dimensional visualisation software that found by researchers from United Kingdom. [164]The software development consists of three parts, GUI, Wrapper and Plug –in. GUI is the main process of the software which is user friendly. All this three combinations tool helps researcher to develop three dimensional visualisation image that produce by electrical capacitance tomography methods. [164]Three dimensional images are very important for volumetric images analysis. [165]The particle volume can be calculated due to the application of upstream and downstream of this tomography system. [189]

For electrical capacitance tomography systems, the image reconstructions are based on variety classical algorithm such as superposition of sensitivity maps, and weighted with inter-electrode capacitance measurements. [153]The new existing image reconstruction algorithm including linear back projection, singular value decomposition, Tikhonov regularization, Newton- Raphson, Iterative Tikhonov, Landweber iteration, the conjugate gradient method, and algebraic reconstruction technique. [175]Back propagation neural network become one of the new image reconstruction approach that's apply for electrical capacitance tomography methods. This new approach, have three layers, input layer, hidden layer and output layer. It consists two training process which is forward propagation of input and back propagation of input signal. [179]

Finite element method is a method that widely used for image reconstruction of electrical capacitance tomography system. This algorithm is applied to obtain more precise image reconstruction analysis. This algorithm divided the fields into many little units and then it build the formula for every unit, then assembled together and lastly it will produce the solution for that image.[180]

To enhance the image reconstruction quality, this tomography method is added with filtering technique. Some researchers also developed new approach known as image composition method that applied in the existence of algorithm to provide better image quality and reduce the computational load. Researchers had proved that the modification of algorithm by using image composition methods has increased the quality of image reconstruction that developed by electrical capacitance tomography systems. [153]

Image reconstruction that produced by electrical capacitance tomography usually displays using Visual Basic, Lab View, and Matlab. Visual Basic is a simple and convenient for system control and image display. For Matlab, it is the easiest software comparing to Lab View because Matlab easy to understand or user friendly, convenient for image display, and has benefit for system optimization. [177]

4.3 Basic Construction of Electrical Capacitance Tomography System

This electrical capacitance tomography methods consist of three main part; sensors, data acquisition system, and computer for reconstruction and viewing images. [151]For sensor it is including a multi-electrode sensor, and for computer software it is for hardware control and data processing including image reconstruction. [175]Figure 1 show the basic diagram of electrical capacitance tomography system. The parameter for electrical capacitance tomography are; the diameter of inner vessel wall, the thickness of vessel wall, the diameter of screening layer, the length and the span of an electrode, the dielectric constant of vessels and the number of electrodes. [172]

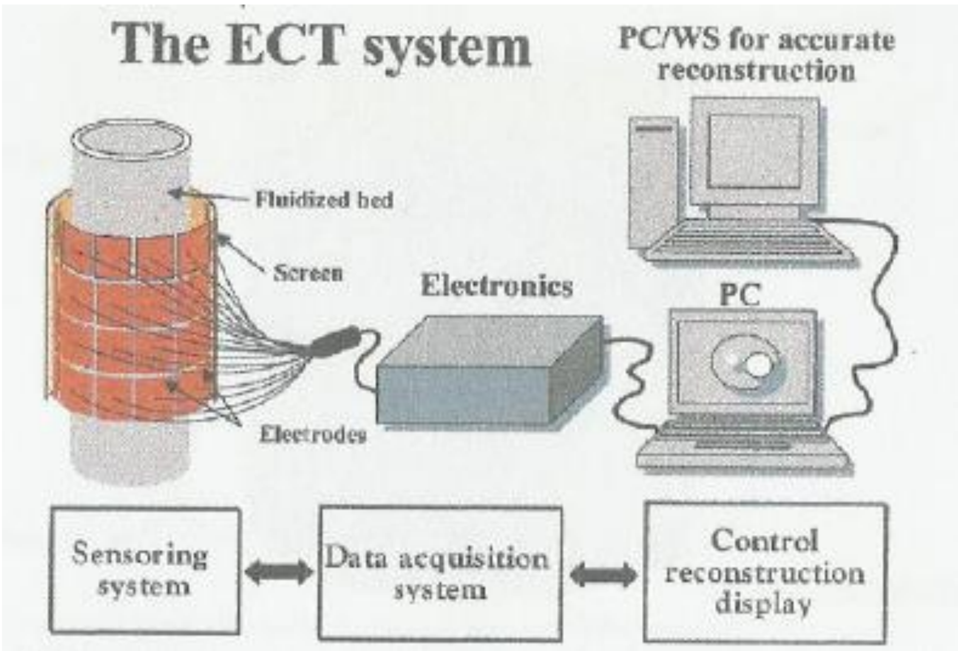

Figure 1: Basic diagram of electrical capacitance system.

There are two types of capacitances measuring circuits, charge or discharge circuit and AC based circuit. These two types of capacitances circuit are suggested to use in electrical capacitance tomography systems because there are immune with stray capacitance. [154]There are three sources of stray capacitance that can affect the quality of image reconstruction. First the stray capacitance is come from the screen cable that connect between electrode and measuring circuit, secondly, it come from CMOS switches that used to select electrode mode and third is come from the sensor screen outside that sensing electrodes that used to prevent external noise. [154]Besides that, there are numbers of electronics circuit requirement to produce a less noise of image reconstruction. The requirements are, the circuit should be robust and less effects by noise, minimum cross-talk between transmitting and receiving channels, and have high possibility to calibrate the receiving and the transmitting circuitry. [155]The robustness of the electrical capacitance tomography system is very important so that this system has high capability to work under harsh environmental conditions. [157]

For sensors, it consist of certain numbers of electrodes plates which are applied around a pipeline. [153]These electrodes plate are applied at the outer part of pipelines. Some applications develop these electrode plates' insides the vessel pipelines. But, by applied these electrode plates inside the pipelines can cause erosion, contamination to media and high cost of constructions. [157]But for certain cases where the metal vessel is used, the electrode should be mounted internally and the metal vessels will act as the earthed electrical screen itself. This earthed screen will help to improve the quality of the image by preventing the flux density between adjacent electrodes. [168]

Usually, the development of electrical capacitance tomography use eight to sixth teen numbers of electrodes. [157]Nowadays, this tomography system can handle until sixty four numbers of electrodes plates at certain time. [160] One electrode is use for excitation of current and the rest for detections. Then, the next electrode will take part for excitation of current and the rest for detection. This principle will be continuous for the next electrodes. Then, the voltage potential at each of remaining electrodes will be measured one at a time to determine the inter-electrode capacitance. This measured reading will be represented in a sensitivity matrix map.

The number of independent capacitance measurement is governed by N (N -1) /2 where N is the number of electrodes. [157] According to the numbers of electrodes, small numbers of electrodes need a small numbers of data acquisition channel and this condition can simplify the hardware construction. At the same time, the data acquisition rate is expected to be fast. [157]With this fast data acquisition rate can help increase the frames acquired per second and this is very important to apply for online monitoring to visualize fast dynamic process. By reducing the numbers of electrodes it can improve the axial resolution of the image. [161] But for another perspective, with a small number of electrodes will decreased the numbers of independent capacitance measurements and produce low quality of images. [157] If the number of electrode plates is increased, it will help in increasing the resolution of image reconstruction because of the increasing of capacitance occurred for measurement values and it also will produce a smaller surface area of respective electrodes. [159]

The lengths of the electrode also important part that need to be consider. It is because; the length of electrodes will give high effect to the measurement value. In electrical capacitance tomography system, it is suggested to use the same sizes as the inner diameter of pipe for round shape sensors. [167]Actually, capacitance value is proportional to the axial length of electrodes. For an example, short electrode give a small value of capacitance reading but give wide spatial bandwidth signal. This situation usually depends on the types of process application. [169]

Another approach of electrical capacitance tomography system is by inside–outside electrodes system. This new approach is based on the new orientation of electrodes that can measure inside and outside of multiphase liquid. [156] Figure 2 shows the orientation of electrical capacitance tomography that suggested by researcher for enhancing the image reconstructions. [156]

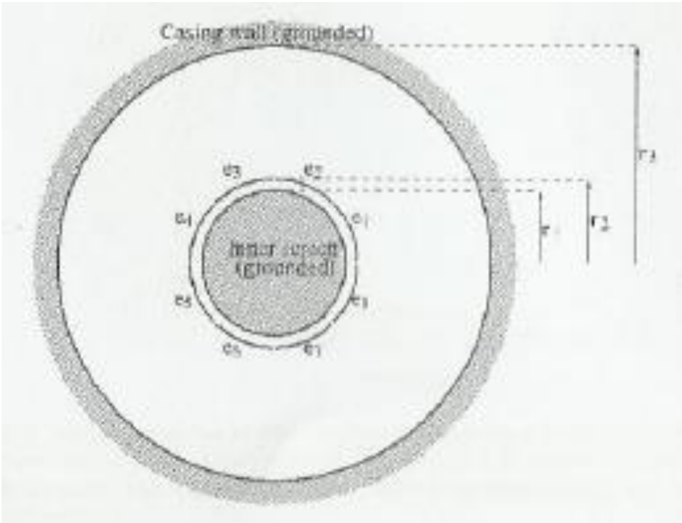

Figure 2: Inside –outside construction of electrodes.

In electrical capacitance tomography systems, the types of vessels pipe are important too. It is suggested to use pure insulator pipeline to give no effects to the measured signals. The thickness and the material of pipeline actually can influence the measurement value. Besides that, other factors such as the corrosion, abrasion, temperature resistance, and temperature stability of pipeline are important to take action. [163]

This tomography method can be applied in horizontal pipeline or vertical pipeline. For horizontal pipeline, it can measure the two or three phase composition which separate layer by layer. For an example, an experiment is carry on to measured two phase composition, air and liquid in horizontal pipeline. From the image reconstruction show that this tomography system not only can measured the distribution of different permittivity inside the liquid solutions, but it also can reconstructed an image of clearly separation of phases. [179] Figure 3 here shows how the image reconstruction for separation phase is look like.

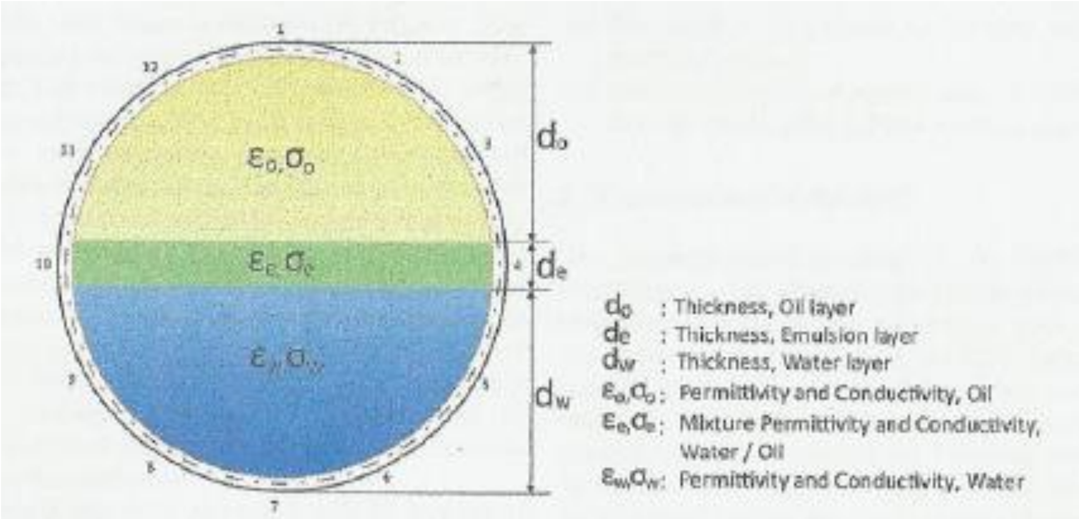

Figure 3: Visualisation of image reconstruction for multiphase process.

Image reconstruction that produce by this electrical capacitance tomography methods have a problems such as non uniform sensitivity distribution, less sensitivity in the central area and non linear change in tomography system. [170] There are also some issues that related with the quality of image reconstructions which are related to the number and length of electrodes, the use of external and internal electrodes, implication of wall thickness, earthed screen, driven guard electrodes, dealing with high pressure and high temperature, twin planes for velocity measurements by cross correlation and limitations in sensors diameter. [157]Another issue that can cause the low accuracy of electrical capacitance tomography system is the particle charging problem. For monitoring solid or particles flow, the particles or solids charging will exist. These charging particles will cause distortion of capacitance measurement value. Particles are charging due to the frictional and collision interactions between particles and pipe wall. [185]All this problems issues should be considered to obtain the accurate data for image analysis using electrical capacitance tomography system.

Earth screen is use for minimised external electrical noise. This earth screen is applied covering the electrodes plate which around the periphery of the vessels or pipeline. Figure 4 shows the construction of pipeline layer by layer. [169]

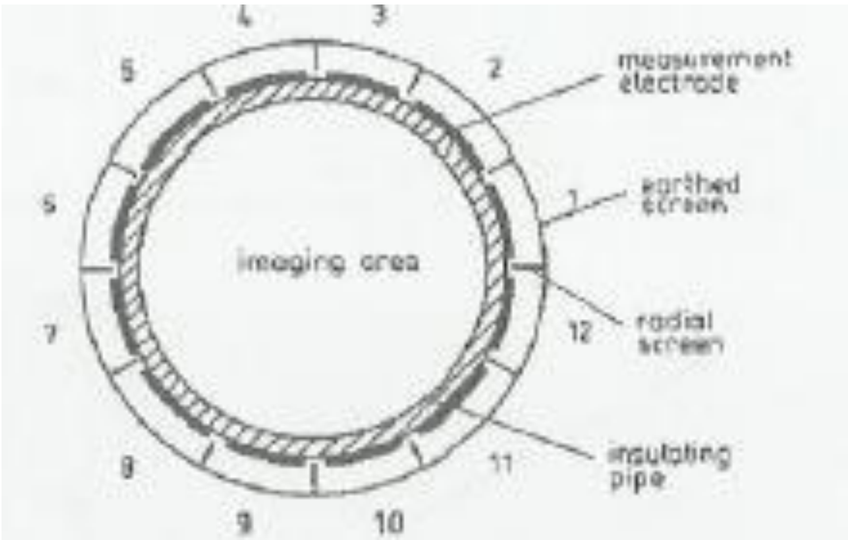

Figure 4: Application of earth screen

Void fraction also results as a problem in electrical capacitance tomography system. Void fraction also known as holdup or fraction that occurred in two or three phase process system. It is a dimensionless quantity and can be defined as a fraction happened in multiphase process system. [191]Actually, electrical capacitance tomography is known as the first tomography method that has been used for multiphase process system. [192] Void fraction is very important for electrical resistance tomography analysis because void fraction can cause a dangerous situation for real time process industries. Measurement of void fraction is very important for safety, environment protection, energy conservation, and quality assurance. [191] This void fraction detection is very important for online flow visualisation because all the data gathered will be use to analysis the void fraction minimum and maximum limitation for safety and ecological protection. [193]

The other way to optimizing the ability of electrical capacitance tomography is by using digital signal processing technique. This digital signal processing technique can improve the performance of the system because high speed data converters, high performance digital signals processors and efficient digital signal processing involved. Besides that, by using digital signal processing technique can reduce the noise effect in electrical circuit. [162]Another approaches that introduced by researchers is using rotating electrodes. To get more measurements reading based on the same numbers of electrode applied, rotating electrode is suggested. By using this technique, electrical capacitance tomography can remeasure the different capacitance at the new orientation and then combining the image result. This technique actually has applied in computerized axial tomography. [173]

4.4 Application of Electrical Capacitance Tomography Systems.

This tomography system method widely use in industrial process. For process industrial, this tomography method is applied for gas or solids flow concentration measurement, monitoring gas or oil void fractions in petrochemical exploration, combustion imaging in flame tomography, measurement in fluidized bed dryers in the pharmaceutical industry and many more. [180]Besides that, this system also applies for agriculture sector such as for root measurement methods. The previous root measurement methods are including destructive cores, pits, excavation, image analysis, X-Ray, and ground-penetrating radar. Some of these conventional methods are expensive. But, this electrical capacitance tomography system is not expensive and good for online or continuous monitoring. [158]

Electrical capacitance tomography system is widely use in today's industry because it is suitable to, monitor their process product output. Comparing this tomography method with gamma radiation meter, this gamma radiation meter sometimes has uncertainty in image reconstruction because gamma beams may hit the process vessel wall while monitoring the process system. When this gamma beam hits the wall, surely changing traversing length beam will occurred and cause error for the image reconstruction. [181]For magnetic resonance and X-Ray computed tomography required a wide space for application because both systems are bulky. Besides that, both systems are expensive and have ionizing radiation. [182]But, for image reconstruction, both system produce high spatial resolution compared with electrical capacitance tomography system. [183] For X-Ray computed tomography and magnetic resonance, the systems required a technical skills including nuclear safety education and training but for electrical capacitance tomography system, it is easy to operate and safe from hazardous ionizing radiation. [184]

Researchers from China developed a high voltage capacitance tomography to full fill the requirement of today's process industries that deal with large equipments. But, this development still in progressing due to the certain issues related such as the size, material, and screen layer sizes. [172]

Electrical capacitance tomography also has been used for bubbles detection in liquid measurement. The existence of bubbles can detect by this instrument because bubbles have low permittivity compare to the liquid because of the atom distribution. Usually, this tomography system is applied around the pipeline for more than one periphery planes. This construction of system can captured three dimensional image bubbles. The changes of the bubbles sizes also can be captured because bubbles sizes increase continuously until they reach a maximum sizes at a distance away from the gas distributor. That is the reason why this tomography system should has capability to measure three dimensional images and can be use for online monitoring. [186]

This tomography system also applied in today's process industries for reducing the air pollution or air emissions from their production that can cause global warming problem. [187]To control the air pollution, this system is applied at the cyclone separator to monitor the percentage of industrial wastes not exceed than the safety level. [187]This tomography system can produce an image that shows the different value of permittivity of gas wastes. Electrical capacitance that applied in fluidised bed dryer has another problem that affects the accuracy and the quality of image reconstruction which is related with the moisture effect. [188] In reality, moisturiser usually can give the changes of electrical properties of material involved and this will affect the permittivity measurement value.

4.5 Conclusions

Electrical capacitance tomography method is widely used in process industries due to it characteristics such as non invasive instrument, no ionizing radiation, high speed for online monitoring and capability to differentiate conductive or non conductive particles. [195]This electrical capacitance also has high capability to measured and captured image of high shear mixing and granulation monitoring. This capability of electrical capacitance tomography system has shown that it is high speed measurement system because it also can detect and captured variety speed of process mixer involved. [196]From the image reconstruction that produces by this tomography system, it can help the researchers to analysis the quantities parameter, velocity and concentration of solid or liquid mixture. [197]

Many research need to be done for future development of electrical capacitance tomography such as an analysis of the construction of this system to be more simple but high capability, analysis on the different shape of pipeline to produce high quality of image reconstruction, and analysis on the sizes of electrodes that capable to measure different dimension of pipeline.[198]

Besides that, new approaches and new development that introducers by researchers for optimizing electrical capacitance tomography system should be applied and commercialized in today's process industries. At the same time, process industries also have to take part in this development by evaluating the potential of this new inventions in helping them providing high productivity and high quality of their production. It shows that researchers and industrial team have to play their part in a way to produce a high quality of electrical capacitance tomography system.

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CHAPTER 5

Optical Tomography System

5.1 Introduction

Optical tomography is widely use in medical and process imaging. For medical experience, this system will measured static subject while for process industrial, this system will measured dynamic process. [203]This type of tomography system is very useful for analysis of internal flow measurement system. This tomography system provides a non invasive cross sectional imaging in biological systems. [200]Tomography system very useful for process industrial because tomography methods is suitable for online monitoring system, alarm function and malfunction detection. [207]This tomography method is the best method compare to other tomography method because the optoelectronics sensors has high speed of light that can make the response time negligible , produce small wavelength that can provide high resolution and measurement are immune from electrical noise. [208]Besides that, this method is straightforward, low cost, and has better dynamic response. [204]It is very important to apply in industries because this tomography system can help manufacturer troubleshoot certain part only. [206] Optical tomography system is a hard field sensor where its sensitivity measurement is independent of the distribution of the measured parameter insides and outside measurement area. [204]This optical tomography method also used in process industries to investigated mass flow rate, velocity profile, and concentration profile. [203]In optical tomography method, there consists of seven different types of methods. There are; optical projection tomography, laminar optical tomography, diffuses optical tomography, fluorescence tomography, optical coherence tomography, acousto-optical imaging, and photo-acoustic tomography. [198] **Figure 1** below shows how all sevens methods of optical tomography transmit the source of light from transmitter to receiver.

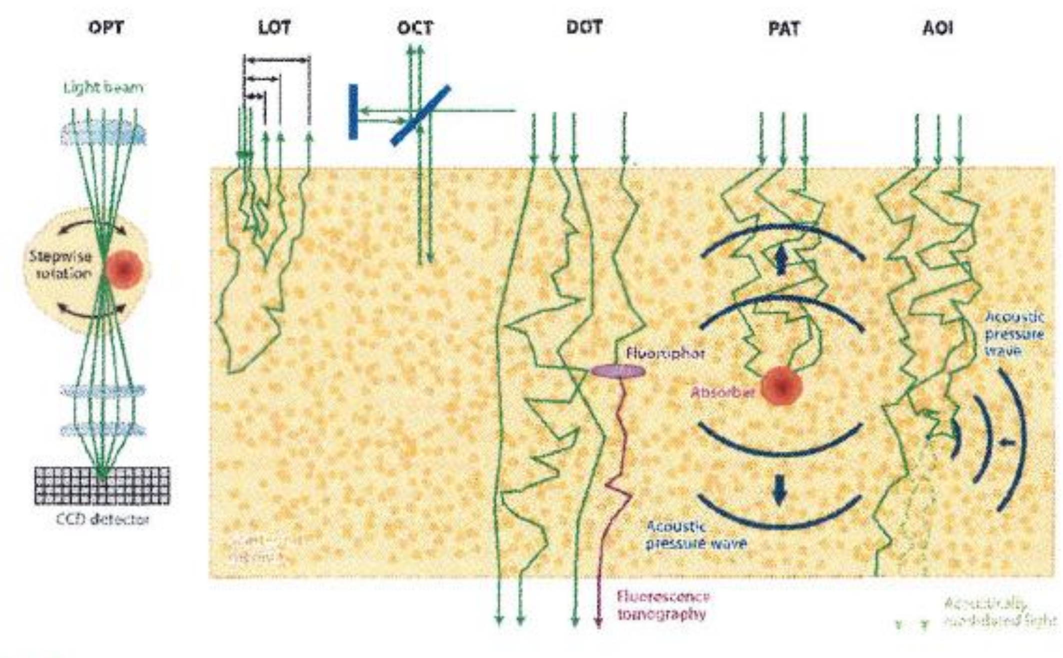


Figure 1: Methods that can be used in optical tomography [198]

Optical tomography system firstly spread out in medical imaging field. For medical imaging field they used optical coherence methods. This method is being chosen because this imaging technology can produce high resolution cross sectional images of the internal microstructure of living tissues. Optical coherence concept is based on the reflection of the light. [199]This optical tomography method used low coherence interferometer to produce two dimensional images. The main criteria that had been used in this optical coherence tomography is low coherence light and ultra-short laser pulse. [201]To enhance the image reconstruction that produces by optical coherence tomography, researcher developed new invention called as quantum optical coherence tomography system. [200]

5.2 Basic Construction of Optical Tomography System

Optical tomography system consists of hardware and software. For hardware, the selection of transmitter and receiver should be synchronous with each other. The right selection of transmitter and receiver is very important to produce high quality of image reconstruction. The main concept of optical tomography to read the data obtained from the hardware is base on the intersection of light beam and particles flows. More particles that intersect with light beam, the higher the voltage produce. [204]

In optical tomography system, the word projection is used to show the arrangement of transmitter and receiver. A projection is formed from a combination of views. View consists of a pair of transmitter and receiver. There are four types of projections; parallel projection, fan beam projection, ultrasonic pulse echo projection and electrostatic field projection. Parallel projection is usually used in radiation methods.[211] Narrow projection is required for parallel mode because it need to focus to the correct receiver. [210] Fan beam projection used single projection from a radiation source and this source of light is converging to the numbers of detectors. For ultrasonic echo projection, it is based on the propagation of a short pulse of ultrasonic waves and measurement of travel time. While for electrostatic field projection, electrostatic field sensing zones are produced by capacitance plate sensors. [211]In optical tomography method, there are two types of projections, parallel beam and fan beam projection. For parallel beam, the sensors have a narrow angle beam while for fan beam projection, it used wide angle beam. [203] **Figure 2(a), 2(b), 2(c), 2(d)** shows the four types of projections. [211] The type of projections for optical tomography play important role to give good image quality which can defined by peak signal to noise ratio and normalized mean square error parameters. [210]

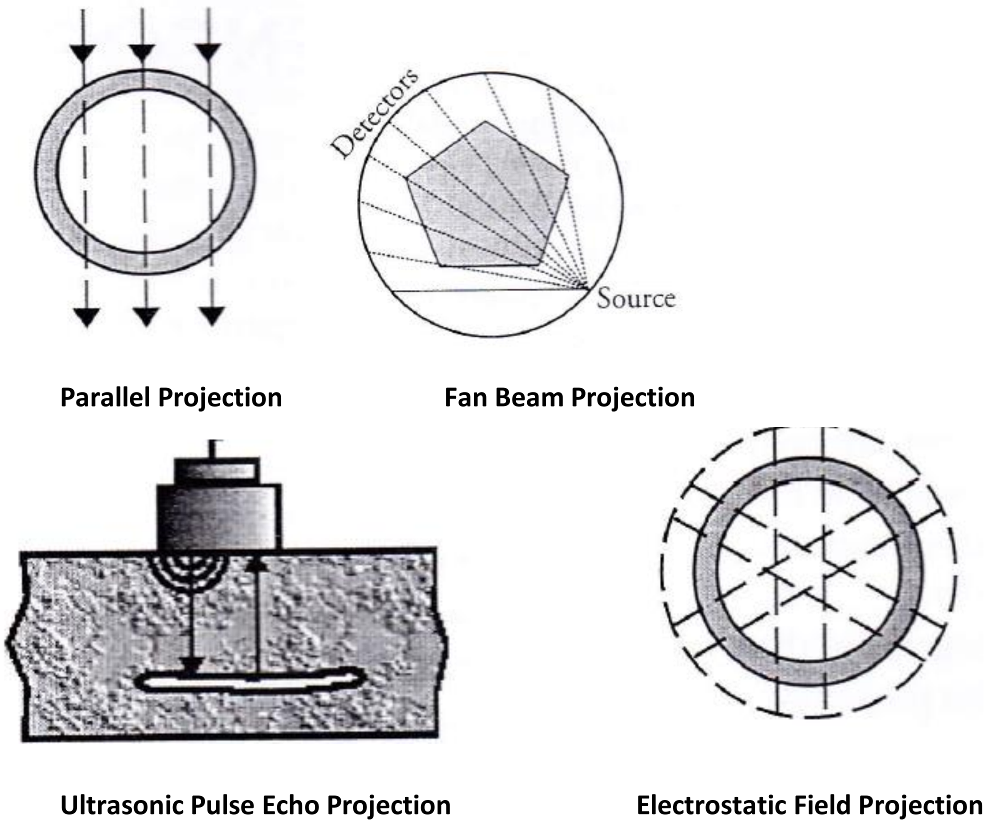


Figure 2: Four types of projections

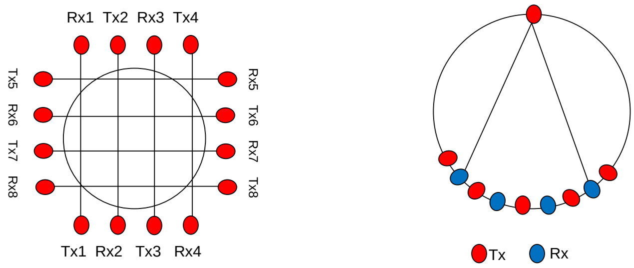
5.3 Recent Research in Optical Tomography.

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].

5.4 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.



(a) (b)

FIGURE 2**.** a) Parallel beam projection, b) fan beam projection

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 spo~~r~~t 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 mod,

f) laser and fan beam mode and

g) dual mode.

5.4.1 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 x 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 1 l/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 3 l/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.

5.4.2 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] and [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.

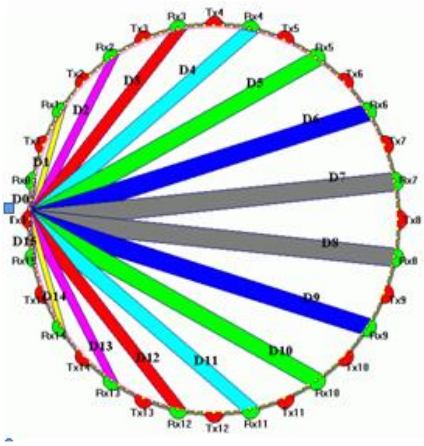


FIGURE 3. Sensor arrangement used 16 pairs of sensor

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.

5.4.3 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 unaffected 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 x 2 x 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.

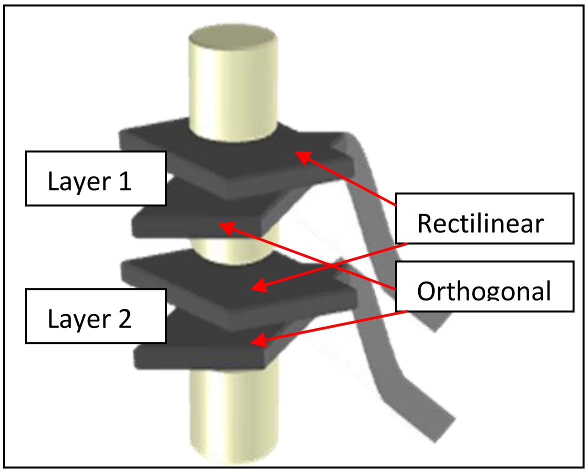


FIGURE 4. Two layer of projection by Pang

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 velocity profile 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 = 2.54 mm). 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 x 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

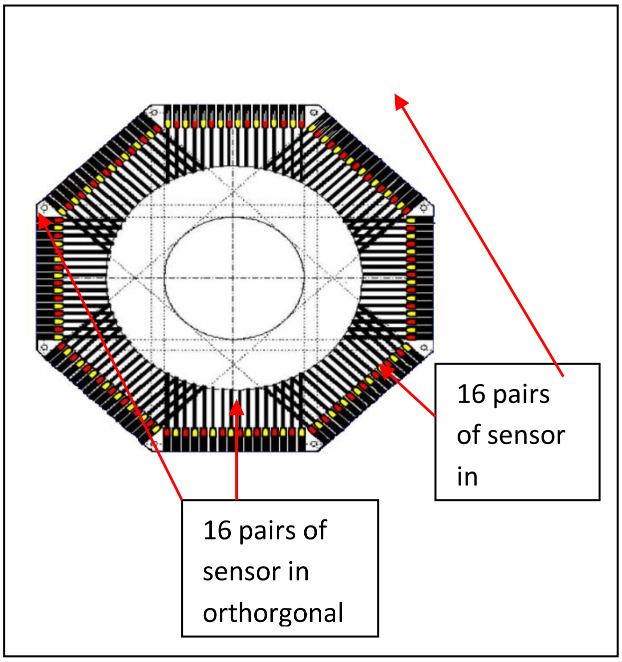


FIGURE 5. One layer of sensor jig by Goh

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 × 8 and 16 × 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 x 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.

5.4.4 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.

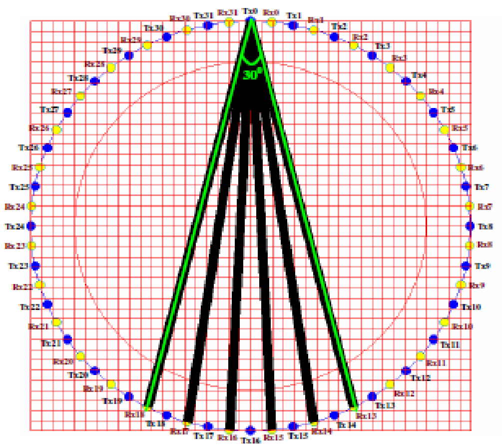


FIGURE 6. Sensor arrangement using 32 pairs of sensor.

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.

5.4.5 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.

5.4.6 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.

Yingna *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. Yingna *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. Yingna *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 3 mm, 5 mm and 7 mm 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, and cannot be applied to industry. 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.

5.4.7 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.

5.5 Summary.

According to previous researchers, Leong [8], Chan [10], 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].

5.6 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 Zhaou *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.

5.7 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 x 8 sensors pairs, therefore, the size of pixel becomes 8 x 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.

5.8 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 x 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 (6 mm diameter), medium sized pipe (2.7cm diameter) and a large sized pipe (4.24 cm diameter) were used as samples to be imaged. The results are shown in FIGURE 7.

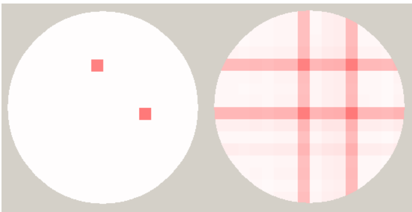


FIGURE 7. LBP algorithm

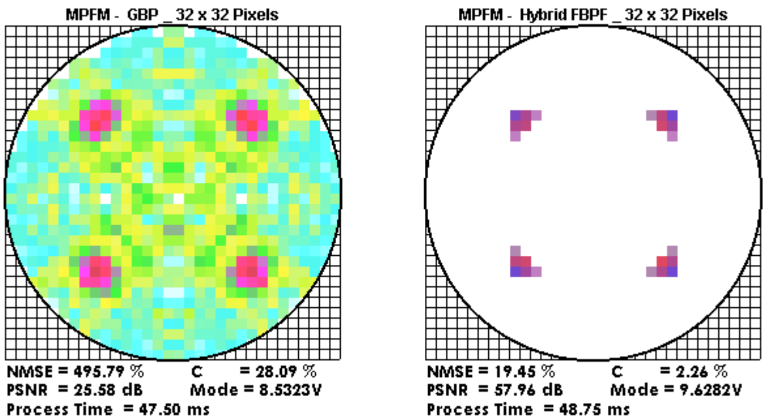
From FIGURE 7, each sample was shown with image reconstructed using Hybrid algorithm on the left and LBP algorithm on the right. The two pixels shown in the first image represents the two small sticks. The second image seems like four pixels due to ambiguity.

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.

5.9 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 10^{th} Iteration method provided more accurate image than LBP [16]. But, only 24 fps can be obtained for LBP and 4fps for reconstruction using 10th iteration. This means although 10^{th} 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 1179.454 g/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.



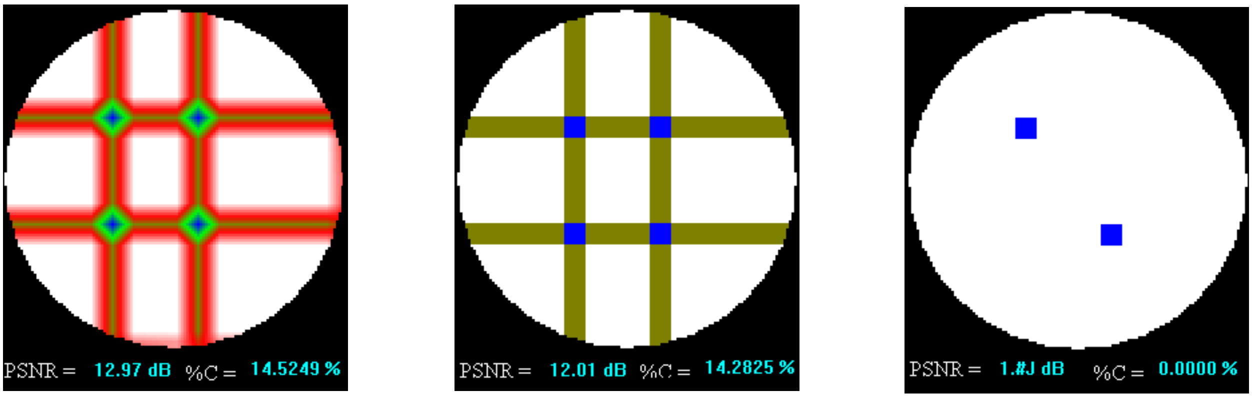
(a) (b)

FIGURE 8: Image of (a)pure GBP and (b)FBPF +HRA

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].

5.10 New Algorithm.

In research by Goh, each rectangular consists of 16 x 16 pixels for image resolution of 256 x 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.



(a) LBPI (b) LBP (c) DSBP

FIGURE 9. Image of different image reconstruction algorithm

Yan *et. al.* [26] used genetic algorithm which was based on the natural selection and evolutionary process, and it involved 60 x 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 x 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*.

Yingna *et. al.* [24] choose the least square algorithm with constraints (LS) to reconstruct the object field distribution. The number of total pixel was 15 x 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.

5.11 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 Yingna *et. al.*[24] which they proved to produce a good quality image.

5.12 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.

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CHAPTER 6

Ultrasonic Tomography

6.1 Introduction

Ultrasonic tomography system is other types of tomography method that widely used in process industry and in medical field. Ultrasonic tomography concept is based on the incident of ultrasonic waves and objects. The frequency of ultrasonic waves can be used in this system is within 18 kHz to 10MHz. [301] Ultrasonic waves is produce by ultrasonic generator. The components that involved in ultrasonic tomography system are ultrasonic generator, transducers, and computerized image processing system. [301] Ultrasonic transducer is an electronics component that converting electrical energy into high frequency sounds wave. Then this sound wave will be transmitted in one direct line. When this source of wave hit onto the objects or any substances surfaces, this sound wave will reflect back or being absorbed by the objects or substances itself. The internal construction of ultrasonic transducers is; it consists of piezoelectric crystal material that can transform mechanical energy into electrical energy. [329]

Ultrasonic tomography system has the capability to reconstruct an image of solid object distributions in air. There are multiple projection can be applied in tomography system to gain high accuracy of image reconstruction. For ultrasonic tomography, a fan beam projection method is suggested. There are many advantages that provides by ultrasonic tomography system. There are; low cost, ruggedness, and ease of integration in computer controlled systems. [318]Ultrasonic tomography system also can be use for safety monitoring in industries. [345]There are many types of tomography system that being used in today's industries. But, each tomography has their speciality. For ultrasonic tomography system, it has being proved that this system has capability to be used for void detection in dry and wet brickwork compared with complex resistivity tomography method. [334]

The basic principal that being used by ultrasonic tomography is base on the time of flight or amplitude of tomography signals. This type of sensor is based on the calculated time arrival of ultrasonic wave after being reflected by an object. [326]Ultrasonic Transducer will emit an ultrasound signal and when this wave is hit the objects, the object may reflect or may observed some of the wave signal. This depends on the types of objects being measured too. Time of flight here means is the time of the reflection being detect after the collision with the objects or substance measured. This time of flight will be considered as data obtained before system can reconstruct an image. [324] Ultrasonic tomography system is recommended to be used for measured spread volume fraction in multiphase flow, transmission and attenuation of ultrasonic. However, ultrasonic tomography system has it limitation in phase volume fraction measurement. [332]

Ultrasound has high frequency sound wave that is higher than the range detectable by human ears. But, for animals, this ultrasound signal is used as their sense to detect the distance of objects or it becomes one of their communication methods. [313]Ultrasonic tomography system produces uneven ultrasound energy waveform. This uneven distribution will cause different qualities in different regions in imaging domain. Hessian matrix is one approach that being introduced by researchers to help to solved these issues. [333]

Ultrasonic tomography system involved an inverse analysis of data measurements. [337]For image reconstruction, there are three types of reconstruction algorithm can be applied; linear back projection algorithm, hybrid reconstruction, and hybrid binary reconstruction. But, the performance for each algorithm is different with each others. [314]From the combination of many angles of measurements; ultrasonic tomography systems allow a map of propagation velocity to be determined by inversion method. [337]

6.2 Basic Construction of Ultrasonic Tomography

The basic components in ultrasonic tomography system are PIC microcontroller circuit, amplifier circuit, transmitter excitation circuit, and receiver circuit.

For ultrasonic tomography, the arrangement of transducer is based on fan beam projection. **Figure 1** shows how the orientation of transmitter and receiver in ultrasonic tomography system. There are two types of projection that can be used in ultrasonic tomography; parallel beam projection and fan beam projection. [303] For Figure 1 below, it show the fan beam projection of orientation applied. From this picture, it show that ultrasound wave from transmitter is hit on to the object or bubbles surface which is yellow in colour. Receiver only receives some of the ultrasound wave because some of the ultrasound wave has being absorbed or reflected back by the objects. This is the way how ultrasonic tomography working.

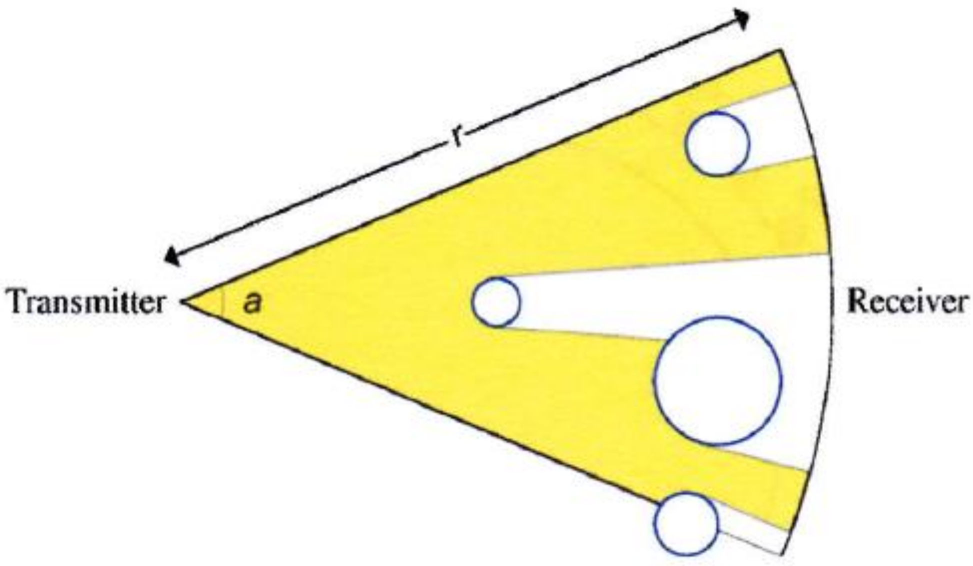

Figure 1: Fan beam projection. [302]

Figure 2 shows the arrangement of ultrasonic transducer on the diameter of pipeline. [339]From figure 2 below, the cross section of ultrasound wave will provide information such as shape, location, and size of the multiphase media and this information can be used to obtain qualitative and quantitative data to model multi-fluid flow system. [339]

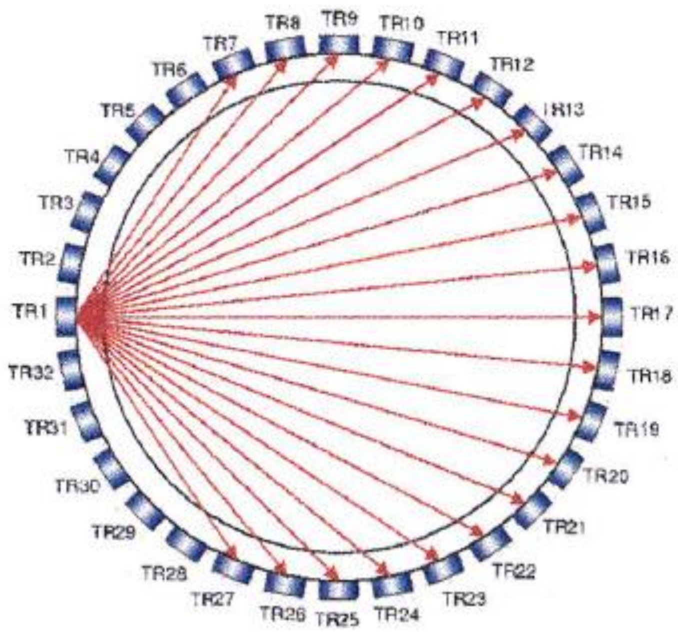

Figure 2: The arrangement of ultrasonic transducer in pipeline.

There are two types of ultrasonic signals, which are continuous signal and pulsed signal. This ultrasonic tomography system also has three types of mode, transmission mode, and reflection mode and emission mode technique. Transmission mode based on changes of transmitted acoustic wave that cause by the material of the medium in measuring volume. For reflection mode, it is base on the reflection on the physical properties. While for emission technique it is based on the measurement of intensity and the spatial orientation of the radiation, emitted from the inside of the measurement plane. [311]

Unfortunately, this ultrasonic tomography system also can have high contrast in acoustic impedance and researchers have developed a mathematical model to solve these problems. From this establish algorithm, researchers can reconstruct a two dimensional image of bubbles in various type of liquid medium. [303]Actually, ultrasonic tomography system has high sensitivity to sound changes. [311]To deal with these problems, a simulation and an experiment is suggested to be conducted before validated the data observed using ultrasonic tomography system. [303]

For the system that applied ultrasonic tomography only, it is known as single modality approach. For single modality approach, it is not suitable for monitoring multiphase flow monitoring process. [310]Some researchers suggested in having dual mode tomography system for increasing the quality of image reconstruction. This concept has been applying in many others tomography system. Researchers from Process Tomography Group in University Technology of Malaysia have made a new dual modal tomography system which is the combination of ultrasonic tomography system and electrical resistance tomography system. From their observations, this dual modality system can give high accuracy of image construction of detecting bubbles with different sizes in the centre of acrylic vessel. [309]

Other new invention that based on the construction of ultrasonic tomography system is by using transceivers. Transceivers are the combination of transmitter and receiver wording. This electronics component is rarely used by researchers. Actually, by using transceiver components, ultrasonic tomography system can overcome the problems such as more space is no more required to mount the sensors. Besides that, it can produce a low cost of instrument and accuracy of the measurement will be increase. The most important things to take note is the way how this ultrasonic tomography system can interact between the incidents ultrasonic waves and the object to be images. [312]

Others approaches in ultrasonic tomography system is related with the mode of each transducers selected. Previously, there are variables mode being introduces by researchers to gain a high quality image reconstruction. Generating guided waves by selecting modes is introduced by researchers. Another approach is using pulse echo measurement. Lamb wave is other methods that can be applied to obtain almost covered the whole object which needs to be measured. A Lamb waves guided is generated to form a series of helical zigzag path. [324]This lamb guided wave is guided the ultrasonic waves that can transmit over large distances in elastics plates and this make them very sensitive for plate defects and useful for non-destructive testing of plate like structures. [325]

Multi input multi output nonlinear ultrasonic tomography system is being developed by researchers from China to improved and enhanced the ability of ultrasonic tomography system to captured and produce the best image reconstruction. This multi input and multi output configuration using the propagation and back propagation method. Ultrasonic wave is produce from multiple sources and transmitted simultaneously to probe the objects immersed in the medium. Then the scattered output signal being captured by receiver and being process by computer software to reconstruct a high quality image. [330]

Usually, substance that being measured using this ultrasonic tomography system consist of inhomogeneous distributions of compressibility and mass density. A group of researchers from German has develop a new approach known as plane wave pulse echo ultrasound imaging method to solve the inhomogeneous distribution problems. This new method presented image reconstruction by ultrasound imaging based on delay and sum-beam forming. From the result obtained, the image reconstruction has fewer artifacts and gives higher contrast. [348]

6.3 Applications

Ultrasonic tomography system is widely used in process industrial field and medical field. It is because; ultrasonic tomography is one of the non invasive and non intrusive tomography systems. In process industrial field, this tomography system is used for monitoring the compositions of multiphase flows in pipeline. For medical fields, this type of tomography is known as ultrasonographic visualisation system. This system is used in medical fields because there is no long term side effect. [301]Besides that, this tomography system is widely used in medical fields because it is non-invasive, non-radiant, painless, inexpensive imaging methods and portable. It is very useful for detection bone disease. In medical fields, the main principal of ultrasonic tomography is from the calculation of time speed of wave cross the bone structures. [335]

In multiphase flows in process industries, it is very important to apply tomography system for monitoring process. For an example, in industry that deals with chemical, they need to apply a system that can monitor the oil explosion. So, for this case, ultrasonic tomography system is the suitable instrument to monitor this problem. [302]Besides that, this tomography system also can use for real time reconstruction of flow images.

6.3.1 Ultrasonic Tomography System in Process Industries

Ultrasonic tomography system can be used to measure two phase flow system. This tomography method can monitor the combination of bubbles and liquid medium. For ultrasonic tomography system, it is not suggested to use for pneumatic conveyer because it deal with gasses. Gasses has high speed of atomization where ultrasonic cannot capture high velocity of gasses movement. But, ultrasonic tomography system can be applied for hydro cyclone system monitoring. Hydro cyclone is a system that used to separate particles from slurry. [304]This tomography method can measure and reconstruct an image that based on the size, position and movement the mixing of slurry. This tomography method is applied to monitor hydro clones system that deals with chemical and minerals. [304]

Industries that deals with chemical, petrochemical and biochemical processing always need a real time monitoring system to monitor their process for control product quality or security purpose. Bubble columns is widely use in industries to perform converting activities such as converting gas to fuels or chemical or gas to liquids. [308]Small gas bubble can be detected by using ultrasonic tomography system nowadays. Researchers have proved that small gas bubbles can be detected using ultrasonic transmission mode tomography system. This type of tomography system is using high frequency of ultrasonic sensors. It is known that higher frequency of ultrasonic transducer can give high sensitivity but lower penetration depth. [328]

Ultrasound computed tomography method is being developed using the same principle of ultrasonic concept. This prototype has capability to access through an irradiated polyacrylamide gel test phantom. The image reconstruction is based on the transmitted signal amplitude and time of flight of ultrasonic wave or signal. This ultrasonic computed tomography method is a new technique using pulse echo imaging that has capability for providing quantitative information of the distributions of ultrasonic properties in polymer gel dosimeter. Polymer gel dosimeter is used for verification of complex radiotherapy treatments. [322]

6.3.2 Ultrasonic Tomography System for Civil Engineering

Geophysical tomography is already developed since 1988. This field of tomography system is related in determining subsurface structures in three dimensional space, borehole and cross borehole data. During this time, a research is carry on by using geophysical ray tomography and geophysical diffraction tomography. [316]

Ultrasonic tomography also used for imaging of structural and geotechnical engineering system. This ultrasonic tomography system is practical to use for civil engineering process because this system has the ability to measure and captures of concrete specimens. [305] Concrete specimens is consists of different sizes of particle and by using ultrasonic tomography system, the measurement of concrete size is based on the travel time between sources and receivers. This tomography system is used in geotechnical engineering because it is very useful for analysis of structural or defect of the state of stress soils. [305]For concrete engineering, ultrasonic tomography system plays an important role to improve quality assurance and quality control during concrete construction. It is suggested to use two dimension ultrasonic signature analysis methods because this instrument has capability to identify subsurface defect. [349]

Ultrasonic tomography system is applied to examine the effects of full scale barge impact testing on bridge structures. This research is carried on the St. George Island Bridge. Ultrasonic tomography system becomes an important tool for this analysis. This system is based on the ultrasonic pulse velocity testing to obtain properties of material by measuring the time travel and arrival to obtain the stress wave through a solid medium. The time travel is used to obtained stress wave velocity.[340]

Besides that, this tomography system is applied for monitoring metallic duct changes in post tension concrete bridge beams too. [350] Ultrasonic tomography is proposed to use for imaging internal structures of metals and concrete. Low frequency transducer with short impulse response is suitable for concrete inspection. It is because concrete usually consist of inhomogeneous concrete structures. [320]

Ultrasonic tomography system is used for detecting damaging monumental stones in Egypt. Usually, deterioration becomes the main factors that can damage the monuments. It results from the different physicals, chemical and biological effects. Sometimes, the humidity, air pollution, biological agents and human activities can cause the damage. Ultrasonic tomography sensor is the useful tools to be used for this damage detection because it is non invasive and non intrusive tools that will not give any effects during the age of monuments. [331] Ultrasonic tomography system also use for soil and rock analysis for long time ago. By using this type of tomography instrumentation, the data obtained is used to provide some average value of measurements of wave propagation velocity. [337]

Due to the progress of ultrasonic tomography system development, a new enhancement known as a fully non- contact hybrids ultrasonic propagation imaging using laser ultrasonic excitation and piezoelectric air coupled sensing is used. This new features can extract the damage crack of concrete. By using this new enhancement of ultrasonic tomography system, surface analysis that based on crack size estimation, and sensitivity can be conducted. [342]

6.3.3 Ultrasonic Tomography System for Agricultural Industries

Wood analysis is very important in today's industries too. Analysis in wood growing is important because wood is an orthotropic materials and the age of wood is depend on environmental growing conditions. [338]There are many types of commercial timber species in this world that valuable for money. For examples, species such as Acacia mangium, Grevillea robusta, and Magiferra Indica are valuable materials. Ultrasonic tomography system is very important tools to apply for investigate the gravity and moisture content that can give defect to the quality of the woods. [344]Due to this defect, it can cause a low quality of timber. Changes in ultrasound velocity will be investigated for wood analysis purpose. [344]

Many types of instrument that is capable to measure wood structured from ionizing radiation to thermal radiation technique, microwaves, ultrasonic, and nuclear magnetic resonance. All this types of instruments are capable to provide a data on wood analysis. By using ultrasonic tomography system, it image reconstruction can be images by time of flight, amplitude, and frequency spectra of waveform. The energy distribution and energy flow are the important energy for enhancing the images contrast. [315]

Ultrasonic tomography system is used for detecting the defect for standing tree. This research is investigated by China researchers. The important of early analysis for standing trees is to detect the deterioration on trees that can harm human or properties. This tomography system can be considered as indicator for standing tree. Image reconstruction of structured internal wood of tree is useful for forest management for further analysis about the percentage of the plant to be standstill for long years. This image reconstruction is providing by the stress wave and ultrasonic wave evaluations. [319]This standing trees analysis is very useful for genetic improvement purpose and for studying wood quality. [327]This standing tree analysis is very important to avoid property damage, personal injury, and loss of life due to the structural defect of age's trees. Ultrasonic tomography system becomes an important tool for accessing tree health. [346]

6.3.4 Ultrasonic Tomography for Food Industries

Ultrasonic tomography system also applied in food engineering. The important of this types of instruments in food industries is used to analysis the properties of food stuff in emulsions, powders, and to detect foreign objects. The basic principle that being used in this ultrasonic tomography system is based on the changes of the acoustic property of the medium must be related with the changes in the foods contents. [317]

6.3.5 Ultrasonic Tomography System in Medical Fields

In medical fields, this type of tomography system is used for breast cancer analysis. This ultrasonic tomography system is known as ultrasonography system. This system can captured images of cancer tissues by using wave collision from the transducers. Usually, this ultrasound system is working with mammography for detecting characterizing the solid masses as benign or malignant. With this combination, the quality of image reconstruction can be improved for further analysis. Besides that, this multimodal system also can capture an image of blood flow and mechanical properties of tissues. [306]The quality of image reconstruction that produces by multimodal tomography system for breast cancer detecting was confirmed by researchers from United State. From their researchers, they acknowledge that this multimodal system is safe and can produce three dimensional images with high quality. It is non-ionising system and not required breast compression as current X-Ray mammography. [307]

X-Ray mammography is a gold standard screening methods in detecting breast cancer but it is not very efficient for women with dense breast. Ultrasonography method is highly recommended by physician because it is more sensitive than X-Ray mammography for differentiate between solids and cystic masses. [341] Figure 3 shows how the breast screen analysis is conducted using ultrasonography system. For patients, she needs to lies on the prone position. The breast is suspended inside a water tank that contains ultrasound sensor. The type of bed that the patient's lies on is allow access to the chest wall and auxiliary breast tissues. [343]

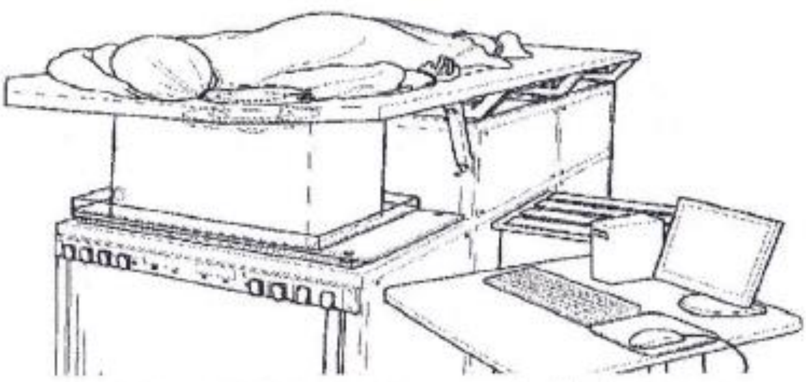

Figure 3: Breast screen analysis using ultrasonography

Ultrasound scan also applied in medical field to detect the health of fetus in mother's womb. The range of ultrasound frequency is between 1MHz to 5 MHz which is suitable for medical purpose. [313]

Ultrasonic tomography system also can be applied for monitoring and diagnosis of cancellous bone and osteoporosis. Osteoporosis is the decreasing of bone mass and the architectural deterioration of bone tissues which will cause fracture risk. [321] Universities in United Kingdom has been recognized the used of broadband ultrasound attenuation for the use of this human problems for diagnosis. [321] Ultrasonic tomography system has capability to reconstruct an image of bones layer by layer for further analysis. Ultrasound system becomes a non invasive system for bone monitoring in medical fields. [347]

6.4 Conclusions

As a conclusion, ultrasonic tomography system is another choice for tomography method to apply in process industries or in medical fields. The main concept of tomography methods which is non invasive and non intrusive system is full fill by this ultrasonic tomography system. This tomography system is useful for medical purpose because no ionizing radiation exist. Besides that, it is easy to implement and need low power consumption and portable. This type of tomography system has been apply for many application including, food industries, civil engineering, medical, chemical engineering and many more. Many new improvements have been introduced by researchers to obtained high quality of image reconstruction for analysis and diagnosis purpose.

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Chapter 7

Positron Emission Tomography

7.1 Introduction

Positron Emission Tomography (PET) is another method that being used in tomography world. This method is applied for medical purpose only because of some reasons. PET widely used in biochemical and physiological processes in human and animals. This type of tomography system is very powerful because it can provide quantitative measurement. [401] PET is a nuclear medicine technique. PET requires the use of isotopes to capture a natural visual imaging process. [415]PET can be a direct imaging analysis for captured an image of growing abnormal cells in human and animal tissues body. [424]

PET also has the disadvantages where the resolution of image is limited by physical factors such as positron range, photon pair nonlinearity, error in localization of each detected photon that result from crystal penetration and scatter within the crystal. [401]To enhance the capability of PET, the combination of PET and CT scanner is introduced. If using CT scanner alone, it gives poor and limited of image quality of soft- tissue.

7.2 Basic Concept of Positron Emission Tomography

Positron Emission Tomography (PET) system is based on the use of radioactive tracer entailing the modelling of the data by a Poisson distribution. [351]This tomography system is very useful to detecting tumours at early stages. PET can be use to monitor patient that under treatment because it can visualize an image for an example glycol tic activity. [409]Whole body PET is attractive in oncology because many tumours preferentially take up F-fluorodcoxyglucose. By using the combination of PET and CT scan, the functional and anatomical information can be provided simultaneously. [423]

Positron emitting isotopes of carbon, nitrogen, and fluorine can occur naturally in many compounds of biological interest and can incorporated into wide variety of useful radiopharmaceuticals and collimation that done electronically. PET is very expensive especially when the short half life of most positron emitting isotopes required an onsite cyclotron and the scanners themselves are significantly more expensive than single photon camera. [414]

7.3 Application of Positron Emission Tomography

Positron Emission Tomography widely applied for medical purpose. PET has the ability to detect lung cancer at stage one. This is very important part in medical to detect cancer at early stage. For this case, CT scan is used and PET become the another medical instrument to clarify the result from CT scan. [402] Lung cancer is the leading cause of death and the optimal treatment for early stage non small cell lung cancer is surgical resection. [423] Tumour hypoxia usually causes lung cancer. This type of tumour results from imbalance between oxygen supply and consumption due to an abnormal structure and function of the micro vessels supplying to tumour. PET is a non invasive instrument to detect the existence of these tumours. PET also can generate three dimension of image and multiple tumour sites can be measured too. [403,419]

Detecting of thoracic aortic prosthetic graft infection at early stage is really needed in medical fields. Computed tomography system can produce an image reconstruction of this problem because it is high resolution system. But, computed tomography system also has it limitation where it cannot differentiate between haematomas and seromas and this make difficulties to distinguish between non-infected and infected prosthetic grafts by using computed tomography scanner. In most cases of thoracic prosthetic graft infection, PET is the suitable system to analyse and visualize this kind of infection. [412]

Coronary artery disease can be detecting using several techniques such as single photon emission tomography, stress echocardiography, magnetic resonance imaging, and positron emission tomography techniques. [413] But PET is the best instrument to visualize coronary artery disease because PET has the capability to detect the location, and compositions of the plaques stenos. PET also very unique because can give reading of quantification of myocardial blood flow in absolute terms and give low radiation dose to patients. [413]

This type of tomography system is used for detecting the existence of oesophageal and gastroesophageal junction tumours. PET has the ability for detecting of these tumours at first stage and after treatment or after chemotherapy.[405] PET also is being as a guide for radiotherapy target delineation. PET primarily performed using F-Fluodeoxyglucose, which is a radiolabel metabolite. PET can be use to monitor the metabolic activity that represents a combination of proliferative activity and number of viable cells. [404]

Another application introduces are the combination of MR imaging, Positron Emission Tomography (PET), and CSF Biomakers in diagnosis and prognosis of Alzheimer disease. This can be called as multimodal tomography system where more than one instrument being combined to gain a high accuracy and high quality of image reconstruction. Each modal have their own capability and advantages in imaging small tissues cells. By this combination it helps doctors to detecting Alzheimer disease accurately. [406]PET is the best selection for detecting Alzheimer disease and neural-imaging analysis because the ability of the compound to rapidly cross the blood brain barrier in amount suitable for non-invasive imaging, selective high affinity binding to the target of interest and rapid clearance from non target brain regions. [411]PET can give high accuracy of Alzheimer disease image reconstruction and can detect at early stage for early treatment. [420]

PET has being proven by researchers for measuring regional bone metabolism. This study is based on the treatment and disease progression in patients with metabolic bone disease and accessing metabolic differences between cortical and cancellous rich skeletal sites. Studying and measuring the effective bone plasma flow, bone plasma clearance and standardized value using F-fluoride positron emission tomography is believe to provide useful information for medical analysis. [407]

PET has the ability to detecting the central diabetes inspidus. Usually, MRI and Computed tomography system will be used for captured an initial image. After treatment, PET is used for monitoring and to show a significant reduction in metabolic activity online. It is because PET can be considering as a high accuracy image analysis compare to other imaging modalities. [408]

PET is suitable for brain analysis. PET can be used to identify the neural system involved in discriminating the shape, colour, and speed of visual stimulus under conditions of selective and divided attention. The ability for PET to select, focus on a small fraction of the incoming sensory information eases the computational load in analyzing environmental scenes and planning responses coherent with behavioural goals. [416] Tinnitus activity can be monitor by PET too. Chronic tinnitus attack limbic, frontal, and parietal area. Previously, various types of functional and imaging technique have been applied such as Magnetic Resonance Imaging (MRI), SPECT, and Positron Emission Tomography used for identifying brain structures. From the observation of researchers, PET is the most suitable instrumentation for monitoring this problem because steady state PET measurement not very sensitive for high lighting the role of cortical networks in tinnitus in more detail. [410]

Angiogenesis research is one of the improving medical researches nowadays. Angiogenesis is a process involving the growth of new blood vessels from pre-existing vessels. It is normal and vital growth and development is found during embryogenesis. [417] Due to the numerous disorders that are characterized by an imbalance or up- regulations of the angiogenic process, it cause psoriasis, restenosis, rheumatoid arthritis, diabetic retinopathy, and tumour growth. There are many approaches that have been used for monitoring this problem such as magnetic resonance imaging, Doppler ultrasound, and scientigraphic technique. But, Positron Emission Tomography system is the best instrument to trace the development of this problem. [417,425]

PET is being used for detecting and monitoring prostate cancer. Prostate cancer is the most commonly cancer among men and the second cause of cancer mortality after lung cancer. PET or the combination of two modality instruments; PET and CT scan are the best selection tools because both systems possible to perform a contrast of image reconstruction. PET has the ability to visualise different metabolism. PET also usually used for monitoring the growing or the reducing of prostate cancer cells after treatment. [418]

A nano-particle based on positron emission tomography is used by researcher for detection of macrophages in aortic aneurysms. Manocytes or macrophages infiltrate the vessel wall and release proteases among the metalloproteinases that compromise the integrity of the vascular wall through degradation of the extracellular matrix. Monocytes or macrophages have secreted inflammatory process that precede the increase in vessel diameter and involved in aneurysm growth and rupture in animals models. Nano-particles based positron emission tomography is the best tools for this purpose. [421]

Positron emission tomography can be used for detecting ketamine’s antidepressant effects. PET can visualising the image of specific proxy measure of glutamatergic neurotransmission in humans because the glucose metabolic signal is dominated by the uptake of glucose into glia in response to neuronal glutamate release. The signal provides a robust and reproducible measure of metabolic activity in neural circuit. [422]

Besides that, PET is used to detect the drug distribution and concentration in vivo in man with the drug labelled with a positron emitting radionuclide that does not change the biochemical properties. PET can be used to evaluate drug interaction with a target, utilising a PET tracer specific for this target, necessities a more rapid development of such PET methodology and validations in humans. [405]

7.4 Conclusions

As conclusions, PET is the best tomography method for visualising two dimensional or three dimensional of tissues cells because it has high contrast and high resolution. The dose of radioactive is small and still under safe amount for patients that being exposed. PET is very useful for detecting and monitoring the growing abnormal tissues before or after treatment. This type of tomography system is worldwide used in medical fields because its capability to capture accurate images of small tissues cells.

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CHAPTER 8

X-Ray Tomography

8.1 Introduction

The development of X-Ray tomography methods has been started since 1970. X-ray tomography method is widely used for medical purpose. Then, this tomography method has been applied in process tomography area too. For X-Ray tomography method, it based on the effect of cathode rays that produced by electrical discharges through gases at low pressures. For X-Ray tomography system, it is large equipment that involved in ionizing radiation. [301]Nuclear magnetic resonance tomography can produce a high contrast of tissues cells, and high spatial resolution. [400]

X-Ray based imaging including computed tomography system, fluoroscopy method, and conventional radiography method. In medical area, the demand of high quality image is increasing day by day. Due to this problem, many new approaches are applied including the introducing of multi modal X-Ray tomography systems. [356]

X-Ray tomography system consists of two main part, transmitter and receiver. For transmitter, it produce coherent X-Ray beam. This X-Ray illuminate an object such as molecule and diffracted photons are measured on a detector. [351]Usually the detector can be charge couple device or a position sensitive detector. [351-352] **Figure 1** shows the system for X-Ray tomography included. When the cone beam X-Ray reach the samples of tissues, photons will scattering on the biological tissues make it an ill-posed problem to reconstructed the three dimensional distribution of the X-Ray luminescent samples. [352]Another source of beam is known as a compact laser driven X-Ray source. This source has small footprint, low cost, and has excellent beam quality. Monochromatic method has helped the beam prevent beam hardening effect serious problem at certain area being measured. This laser driven electron storage ring X-Ray source can give high image quality too. [355]

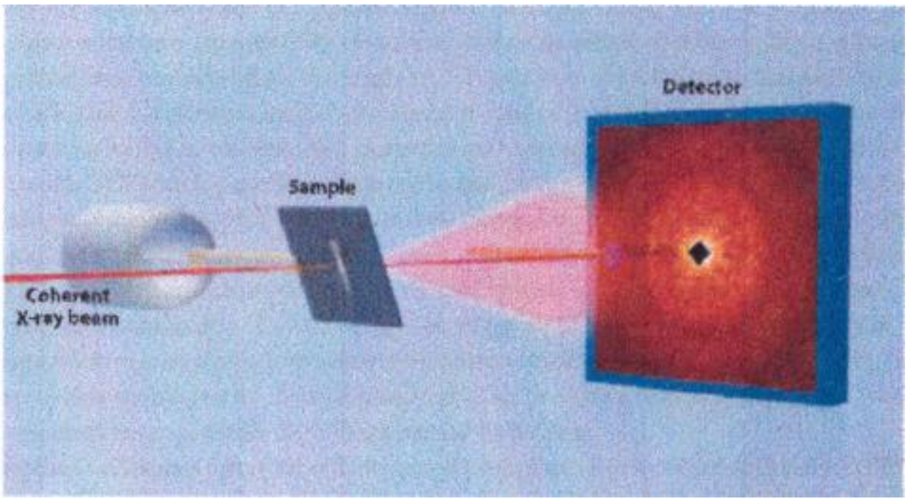

Figure 1: X-Ray tomography system

There are many researches that related with X-Ray tomography system try to enhance the capability of this tool as medical equipment or as process tomography instrument. A group of researchers from German has introduced an advanced approach of X-Ray free electrons lasers. The development of X-Ray free electron laser such as Linac Coherent Light Source in United State, SACLA in Japan and XFEL in Europe, has produce X-Ray pulse with duration down to 10fs and up to photon per pulse. It is because, short wavelength offered by X-Ray, electrons, and neutrons can be used for atomic force microscope. [351] A new design of X-Ray tomography system known as soft X-Ray multi camera tomography system is new prototype that has many advantages such as using low neutron activation materials, and having low magnetic permeability. It also has high steady state operational system. [354]

X-Ray tomography system also has a capability to capture an image of nano-scale of objects or substances. This observation is proved by researchers from Illinois. This new invention of Nanoscale hard X-Ray Microscopy Method has versatile visualisation of material properties. [353]

8.2 Hardware Construction

X-Ray tomography system consists of X-Ray tube and annular detector array with data acquisition system. [375]The basic principal of X-Ray tomography system is, this hardware work base on the beam that being produce by transmitter is sent on the sample that mounted on a rotator or other static place. Then, a series of N radiographs corresponding to N angular positions on the sample in the beam is recorded on a detector. The best detector is charge couple device detector. [362] Charge couple device has high precision and it usually mounted in a U shape arm and this U shape arm rotates 360 degree. [371]Finally, the radios are used by a reconstruction software to obtain the three dimensional distribution of the linear X-Ray attenuation coefficient. **Figure 2** shows the basic flow of X-Ray tomography system. [362]

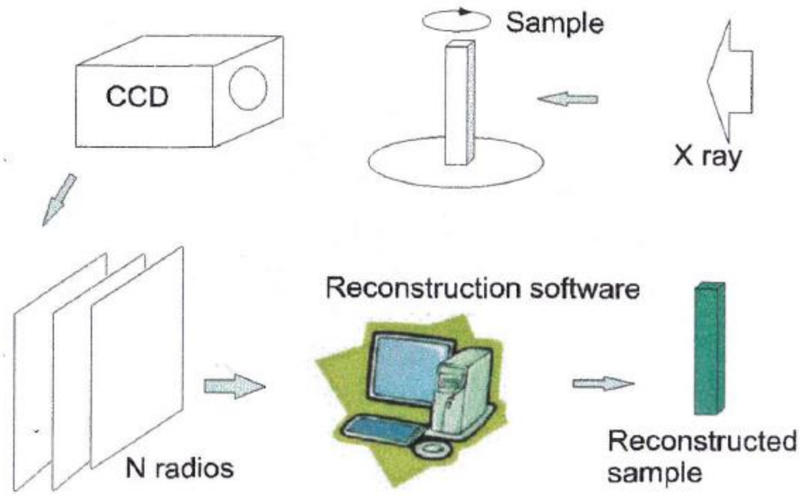

Figure 2: Basic flow of X-Ray tomography system

X-Ray tomography system is produce in highly evacuated glass bulb of an X-Ray tube consisting of two electrodes; platinum or tungsten. High voltage is applied within these electrodes and this situation will accelerated electrons to produce X-Rays electromagnetic radiations as they strike the anode. High speed electrons will produce radiations as they are decelerated by positive charge nuclei of the anode material. [372]

To solve the image reconstruction problems, there are two types of mathematical that can be used. First one is algebraic method which consists in solving a linear system of equations and analytical methods which principal is to back project the transmitted intensity. Generally, analytical methods are faster than algebraic methods. [362]

A new invention known as X-Ray micro-tomography system has been design for capturing image of low dose imaging of radiation sensitive living organism. This type of tomography system is suitable to image the early stages. In these types of tomography system, a mini focus X-Ray source is used. [373]

In radiologist fields, a streak artefact usually occurs in the image reconstruction. This problem caused an inconsistency that result from patients' motions, mechanical malfunction of the scanner, data under sampling, partial volume, metal or X-Ray photon starvation. Usually, image reconstruction is applying filtered back projection process. These positive and negative contributions among neighbouring line are combined and no straight lines appear in final images. [374]

8.3 Applications

X-Ray tomography system can be applied for various types of applications. This tomography system is very popular among medical expertise. But, this tomography system is being introduced and popular in process field. X-Ray scattering is popular for complex biological systems. X-Ray scattering has the ability to penetrate and weakly interact with the bare studied material. The advantage of X-Ray scattering is, it is not required any tags, makers or modification to the samples under examination and it is limited by the nature of the surrounding environment. [367]

8.3.1 X-Ray tomography system for process industries monitoring system

This tomography system has been applied for producing three dimensional image reconstructions of gas diffusion layers. The selection of this type of tomography because it has the capability to give high resolution image and improve the knowledge gain from microstructure. A gas diffusion layer is very important in oil and gas analysis because it is very important to improve the fuel cell performance. [357] X-Ray tomography system is suggested to use for microstructure visualisation. [362]

X-Ray tomography methods are used for reconstruct an image of microstructures of carbon/carbon composite to reveal cracks and voids. An X-Ray tomography method is suitable method because it is non –destructive method that can explore the internal material structures. From the three dimensional image structures, the knowledge of their shape, size and distribution can be obtained. [366]

8.3.2 X-Ray tomography system in detection of body packing

X-Ray tomography system has been used as a detector for body packing issues. Body packers referred as swallowers or couriers. Usually, body packers bring in illegal stuff interring country by swallow it. X-Ray tomography system is the best tools that can help police officer to do inspection for this of cases. [358]There are various types of X-Ray tomography system that can be used for this purpose. For an example is, by using abdominal radiography, ultrasonography, multi-detector computed tomography, and magnetic resonance imaging. [358]

8.3.3 X-Ray tomography for silk fibre hydration

The internal nanoporous structures of a single silk fibre under different humidity conditions are very important for silk manufacturing to control their silk quality. Both conditions, dry and humid are important to be investigating. X-Ray tomography has been spread out into material science for imaging purpose. Silk come from cocoons made by silkworm larvae. It is a unique material because it is highly water absorbent, robust and strong. The study of structures of pores, orientations, size and shape is very important because this requirement will lead to give high quality control of silk. [359]

8.3.4 X-Ray tomography for agricultural sector

Previously, to investigate the structures of tissues cell in leaf is using light microscopy. Light microscopy is a confocal microscopy that has limitation view of the sample. Then, researchers found a new methods for leaves analysis by using X-Ray micro computed tomography method. By using this method, a three dimensional images of leaves structures with high resolution can be created and this has help researchers to investigate deeper of leaves analysis. High resolution of plant tissues can be obtained by using X-Ray micro computed tomography system. [360]

X-Ray tomography method is being applied for root analysis. This root analysis is very important to monitor the healthy growth of plant. The methods that is non –intrusive and non invasive is highly recommended for this purpose. Analysis the growth of roots is very important because roots is the place where there delivery the water and nutrients to the plants. This also has an effect by the soil around the roots. X-Ray tomography methods has the ability to visualize roots development and this methods give an advantage for roots analysis for studying the best methods for confirm the healthy growth roots and plants. [363]

Soil structures can be characterized according to the spatial and temporal distribution of organic and mineral particles, water and air. This complex interaction in soil structures required a non-invasive technique for soil analysis. [365] X-Ray tomography system also plays an important role in monitoring the fertilization of soils. This method is very important to enhance the growth and the fertilization of soils quality and productivity. An X-Ray tomography method is the best instrument for soil inspection because it has higher resolution, stronger contrast, and faster scanning speed. These tomography methods also become excellent tools for studying microstructures of soil aggregates. [364]

8.3.5 X-Ray tomography system for water management inspection

X-Ray tomography system is applied for water management monitoring because this tomography tools has the capability to visualize water conditions in three dimensional images. Previously, there are many types of imaging technique that has been used such as optical imaging, magnetic resonance, neutron radiography, and X-ray imaging technique. All this tomography applications has their advantage and disadvantage. For optical tomography system, the pipeline or tank should be transparent for monitoring. While for magnetic resonance, this method has limitation in the temporal resolutions. Neutron radiography gives low temporal and spatial resolution. For X-Ray tomography system, this instrument has high temporal and spatial resolution that suitable for visualising water transportation. [361]

8.3.6 X-ray tomography system in medical field

X-Ray micro tomography has been developed by the researchers from United Kingdom for dental research. This tomography method allowed three dimensional analysis of both structures and density or concentration of mineral quantification. In this development, they use charge couple device as their receiver to provide high quality of image reconstruction. In dental research using micro tomography methods, slight differences in mineral concentration allowed features such as dead tract to be visualised and ion transport from glass ionomer cement into demineralised dentine to be observed. [368]

X-Ray tomography system is being applied for inspection of Gorham disease. Gorham disease is a spontaneous, idiopathic and progressive form of primary osteolysis. Multi detector of X-Ray computed tomography system is the best way to construct high resolution of image reconstruction for those patients who facing these problems. [369]

X-Ray tomography system is used for bone tumours diagnosis. Vertebral hemangioma is one of the sources of bone tumours. It happened slowly without patient notice it at early stage. If this problem is not notice at early stage and patient did not do any diagnosis, it can give worst effect to patient where fracture will caused and or symptom of nerve compression. [370]

8.4 Conclusions

As a conclusion, X-Ray tomography system is one of the best tomography systems that can be used for medical and process industrial fields. It is because this type of tomography system has high resolution and can create a three dimensional images of tissues cells. Unfortunately, the size of this system is high cost, bulky and very sensitive. This X-Ray tomography system is widely used for medical purpose. Then, this application being modified to full fill the requirement for process industrial purpose. This X-Ray tomography system becomes one of the best tomography tools for microstructures analysis.

8.5 Nuclear Magnetic Resonance Tomography

8.5.1 Introduction

This type of tomography system is very popular among medical fields for diagnostics purpose. It is because this type of tomography system is available for measuring high resolution anatomical images. [378] Nuclear magnetic resonance tomography system is suitable tools for imaging tissues contrast in microscopic regime. [390]This tomography system has the potential to visualise internal structures and to monitor physiological processes in vivo. Besides that, this type of tomography tools also has the capability to image the internal structural of plants tissue cells. [394]

This tomography system is a powerful tool to obtain a three dimensional morphological and functional information with resolution millimetre range. [381]But according to researchers from United State, they have found a new improvement or enhancement of nuclear magnetic resonance output resolution that can achieve until nanometre scale. This can happen by using scanning probe technique. [382]That is the reason why nuclear magnetic resonance tomography is popular and very suitable to apply for molecular imaging image reconstruction. This hardware development also becomes the innovative diagnostic tools for early diagnoses and monitoring therapeutic treatments. [383]

8.6 Applications

8.6.1 Nuclear Magnetic Resonance Tomography in Process Fields

This system is applied for process and biochemical engineering too. In process industries, this system is apply for investigating solid fluid suspensions in order to understand suspension theology and flow induced micro structural changes. This type of tomography has high resolutions. [351]The application of this instrument in chemistry, physics and biology can provide a structure and dynamics of matter at the molecular scale. [379]Besides that, this tomography system offers a non invasive instrument, with high temporal and spatial resolution imaging. [378]This is because due to the higher magnetic fields strength and the development of better coils and optimization of radio frequency pulses. [376]Besides that, another approach to increase the high contrast of imaging technique is by applying hyperpolarization technique. This technique is applied by increasing the polarization of nuclear magnetic resonance far beyond it equilibrium. [395]

8.6.2 Nuclear Magnetic Resonance Tomography in Multi Modality System

While multi modality is another approach that being introduced by researchers to enhanced the image reconstruction. Combination of positron emission tomography and nuclear magnetic resonance tomography is another approach that being used to get high resolution image reconstruction of tissues cells. [397]

8.6.3 Nuclear Magnetic Resonance Tomography in Medical Fields

Nuclear magnetic resonance tomography system is capable to investigate anatomic, functional and metabolic imaging. This method can captured an image of delivery of blood to the tissues in perfusion weighted imaging or molecular motion along a fibre track in diffusion sensor imaging. [380-379]

Other approaches that being introduced by researchers is known as singlet nuclear magnetic resonance. This new enhancement has ability to give long lifetimes than the conventional nuclear magnetic resonance tomography. This is based on the modification of slow molecular processes, the elucidation of molecular geometry, and the transport of hyperpolarized nuclear spin order. [384]

In process imaging using nuclear magnetic resonance tomography, an additional agents is applied in the substance that will be measured to give high contrast of it. One of the agents is called as magnetic nano-particles agent. This magnetic nanoparticles agent’s also known as diagnostic tracer. [385]

In medical fields, nuclear magnetic resonance is applied for diagnostic of brain and spine. This is a safety instruments to apply for patients that having above problems. This safety is based on the limitations of radio frequency power and performing close patients monitoring. [386]Magnetic resonance tomography is one of the quantification of mineral levels in the brain. This tomography method also guaranteed a consistent result from exploring microstructural modification at the basal ganglia and mesencephalic levels. [396]

Real time nuclear magnetic resonance method offers a flexible trade off between spatial and temporal resolution.[398]

The combination of magnetic resonance imaging with mathematical and computational technique, modern brain image analysis can be developed for the neuroscientist and clinician. [389]Neuroimaging procedure is related with brain imaging. In neuro imaging, nuclear magnetic resonance tomography is one of the tools that give high sensitivity of image reconstruction. In neuroimaging tools can give high resolution of abnormalities brain.

[387]By using magnetic fields, radio frequency pulse will be tune to generate resonance signals from hydrogen nuclei in neurochemical molecules. This process wills yield a magnetic resonance spectrum with peaks unique to each molecule. The strength of each resonance will reflect the concentration of molecule. [388]

The unique characteristics of nuclear magnetic resonance system to provide a non invasive, quantitative, physiochemical information has attract those fields; chemistry, biology, material science chemical engineering and medicine. [391]This tomography system also has attracted researchers' analysis that involved in of drug delivery using solids dosage forms. [391]

Magnetic resonance tomography system is applied for monitoring glutamatergic system in mood disorders. Glutamate is the major excitatory and inhibitory neurotransmitter in the brain and it involved in all signal processing function of the central nervous system. [393]Some other technique is using multi modal nuclear resonance tomography system that can enhance the ability to produce a high image reconstruction. [392]

8.7 Conclusions

Nuclear magnetic resonance tomography is widely use in medical fields rather than in process fields. This type of tomography system can give high resolution of image reconstruction. But, the sizes of this instrument are very big and not suitable for process industries. This type of tomography system has help medical fields in analysis and diagnostic of variety health problem and disease.

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CHAPTER 9

Microwave Tomography

9.1 Introduction

Microwave tomography system is another choice of tomography methods that applied in medical and process industries. This type of tomography system is using microwave spectrum in detecting objects. This tomography system is based on the contrast in dielectric properties of materials. [428]This type of tomography can be categorized as non invasive tomography techniques and very suitable for soft tissues image reconstruction. By using microwave tomography system, biological tissues can be differentiate based on dielectric properties. For high contrast shows the muscle and low contrast show the fat and bones. [426]This microwave tomography can provide information about the physiological state of tissues as well as the anatomical structure of an organ.

This tomography system can provide a two dimensional or three dimensional of image reconstruction. [429]For three dimensional of image reconstruction, microwave tomography method use at the frequency value of 1GHz.[433] A researcher also has revealed the ability of this tomography system to construct an image of three dimensional of complex internal structures of heart including the right and left hand side. [430]

For image reconstruction, inverse algorithm is used. But, researchers will deal with challenges because inverse algorithm related with linear or nonlinear problems and this sometimes can cause false solutions. [431]Besides that, the image reconstruction also difficult to obtain using non linear problem because not only the parameter are unknown; the fields' distribution are unknown too. [445]A researcher from United State in 2003 has introduced iterative nonlinear inversion method or contrast source inversion method that using multiplicative regulation to be an efficient and accurate inversion technique.[445]Another method that known as Lavenberg Marquardt method is being introduced by researchers for complex permittivity reconstruction for microwave imaging technique. This reconstruction method refers to quantitative reconstruction of the dielectric and conductive property distributions of biological objects. [448]

With this type of tomography system, various types of image reconstruction can be used such as iterative reconstruction and linear back projection algorithm. For microwave tomography method, the quality of image reconstruction is based on the numbers of receivers, the accuracy of scattered field measurement, and the dielectric contras. [432,441]

9.2 Basic Principal for Microwave Tomography

The basic principal of microwave tomography system is based on the frequency of microwave wavelength. This tomography method use the electromagnetic radiation in the frequency range of few hundred megahertz to a few gigahertzes to quantitatively reconstruct the complex permittivity of the object imaged.[436] This microwave tomography system using low power electromagnetic radiation with wavelength in the centimetre range to reconstruct centimetre sized details in the dielectric and conductivity properties of tissues. [450] This tomography method is used for medical purpose because it is low cost, non-ionizing radiation and has the ability to image the large electromagnetic properties of tissues. [436]This tomography method still has the disadvantages. One of it is, this tomography method wave radiation easily being absorb or shielded by the biological tissues. This usually occurred when the receivers and transmitter are place near to each other. Some researchers from Russia advise to use double used of radiation focusing. [443]For microwaves tomography system, an inverse scattering algorithm is use for image reconstruction to reconstruct the shape, location, and dielectric properties of the object of interest from the measured fields. [449]

9.3 Application of Microwave Tomography

Microwaves tomography system is use for medical purpose too. This application starts being applied at early 1980. [446]In medical field, microwave tomography is use for brain imaging. This tomography system is widely used in medical because it is safe, portable and cost effective. This tomography system also offers the potential for diagnosis of functional and pathological tissues conditions including and perfusion related injuries. [427]

Microwave tomography method is applied for breast cancer imaging too. The cancer tissues can be differentiating between the different values of dielectric constant. Some issues occurred because of the imbalance of contrast value. This problem can be resolved by using contrast agents. [434]Breast cancer tissues can be detected by using microwave tomography method because it can produce high resolution of image reconstruction by displaying the location, size, permittivity and conductivity of malignant tumours inside the body. [439]The basic principal that has been used in microwaves tomography for breast cancer detection is based on contrast in dielectric properties of normal and malignant breast tissues. Confocal microwaves imaging involves illuminating the breast with an ultra-wideband pulse from a number of antenna locations then synthetically focusing reflection from the breast. [447]

This application is very important for detection and identification of buried in homogeneities using electromagnetic waves for non- destructive testing applications. By using microwave tomography method, it can provide two algorithms; qualitative algorithm based on diffraction tomography for detecting buried object and second is quantitative algorithm for reconstructing the complex the complex permittivity profile of objects. [442]The main reason why microwave tomography method is very suitable for this purpose is because the ability of microwave spectrum to penetrate through non metallic wall. The frequency band is within 900MHz to 2.5GHz. This tomography method has high spatial resolution too. [444]

Microwave tomography method can be use for ground penetrating radar. The use of microwave tomography is for localizing and sizing the buried objects. [438]This tomography method can apply for through wall microwave tomography. This type of tomography system has the ability to cross section imaging of dielectric and metal objects on the other side of a concrete wall and within a concrete block. [440]

This microwave tomography method is applied for penetration through opaque media especially for process industries. This development of tomography method is base on the sensitivity of microwaves propagation constant upon quantities such as water contents, temperature or compositions. [446]

9.4 Conclusions

As a conclusion, this microwaves tomography method is another non invasive and non intrusive tomography method that can applied for medical and process industries. This tomography method is one of the method that using spectrum wavelength. This tomography method is non ionizing radiation and it is safe for human and other objects. But this tomography method has it limitation based on the dielectric contrast and researchers has introduced variety methods and approaches to deals with this problems. Beside that researchers also introduces many algorithm to help enhanced the quality of image reconstruction.

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