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A Review Relations of Optical Tomography and Optical Coherance Tomography

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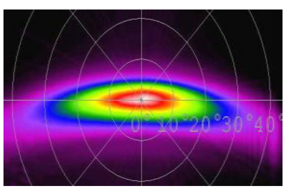
Graphical abstract



Abstract

Optical Tomography (OT) is a form of computed tomography using a digital model of the volume of an object by reconstructing an image of the light transmitted and scattered by the object. OT is used mostly as a form of research in medical imaging. OT depends on the reference object being at least partially light transmitting or translucent, so it works best on soft tissue, such as breast and brain tissue. Optical Coherence Tomography (OCT) is a new technology for performing high-resolution cross-sectional imaging. OCT is similar to ultrasound imaging, but uses different types of light instead of sound. OCT can provide cross-sectional images of tissue structure on the micrometer scale and in real time. OCT serves as a kind of optical biopsy and is used as a medical diagnostic imaging technology because, unlike conventional histopathology, it does not require the removal and processing of tissue specimens for microscopic examination. The study was carried out to see how the two types of optical imaging and the use of concepts and components used in the system. The light source is used to show different levels of penetration and resolution for both methods is used. The use of an interferometer in optical imaging applications is discussed along with examples of commonly used methods. The optical imaging method contributes significantly to the diversity of tomography systems.

Keywords: Optical tomography; optical coherence tomography; light source; interferometer

1.0 INTRODUCTION

The word ‘tomography’ comes from the Greek ‘tomos’, meaning the phenomenon of cutting or slicing (slice). Tomography is a technique used to produce a cross-section image of the internal structure of an object by use of photons or particles that can penetrate objects and can be analyses for the purpose of obtaining the results of the monitoring of the installed detector system.

Generally Optical Tomography (OT) is used to reconstruct an image produced by optical radiation; the OT system emits a beam of light from the border and receives the light beam from the border. This is because there are no harmful radiation effects. In addition to its use in medical applications, it has already been widely used in industry.

In addition, the optical monitoring system has become a popular choice in industry due to the low prices of optical transducers and quite simple and easy operation compared with other sensors such as capacitance sensors. An optical sensor is capable of measuring a high speed particle flow because it can provide a fast response time.

2.0 OPTICAL TOMOGRAPHY.

An Optical Tomography (OT) is a system that depends on the object under study from the refracted light transmitting part or translucence on the surface of soft tissue of the human body, OT can also related to other name: Diffuse Optical Tomography (DOT), Photon Migration Tomography (PMT), Photon Migration Imaging (PMI), and Diffuse Photon Density Waves (DPDW) [1].

An optical imaging technique for imaging the breast has been evaluated to describe a simple breast transillumination system [2]. Another sophisticated form of breast transillumination is called diaphanography [3]. In this technique, a 35 mm camera with infrared sensitive film is applied to photograph the breast, which is transilluminated by a high intensity strobe lamp contained within the light source. A dual wavelength pulse light source is used in the digital spectroscopy technique to evaluate the optical transmission characteristics of the breast image [4].

OT is one of the concepts by scanning light to inside of the pipelines for assist the process monitoring whether air bubbles or particles which are not required [5]. If there are impurities passing through the pipeline in question, they will lead to differences in the voltage and a lower reading from the sensor will be received by the recipient. Input signal from sensor by voltage is used to generate the image in the imaging process [6]. The projections of the sensor, transmitter, and corresponding receiver circuit are required to drive the infrared (IR) Light Emitting Diode (LED) sensor. For OT system operations, there are several steps to be followed. Based on Figure 1, one of the transmitters has been activated (Tx0) while the rest of the transmitters (Tx1 to Tx15) remain off. At the same time, all recipients (Rx0 to Rx15) receive the signal for further processing. The same process will be repeated until the transmitter Tx15 is reached. The signal received in the form of an alternating voltage difference value is converted to a digital signal by processing of the data by a computer for reconstruction of the image.

Basically, the system is divided into three main sections. The first part is the observation or monitoring object detection sensor, the second is the sensor data acquisition part, called the receiver, and the third consists of processing the set of data received from the scanning process, where analogue data received (alternating current) will be processed into digital form (direct current) so that they are appropriate for computer analysis [7]. Duration for OT processing occurs at the speed of light it refers to the process of transmitting data at high frame rates [8].

Light sources using an LED device as a switching system design are cheap, and some use a laser with high pressure [9]. This system produces results with real-time monitoring undertaken as an ongoing process. The beginning of the development of this system use 32 pairs of LED and Silicon PIN diodes. This component is used in studies for the monitoring of the distribution of particles and the effect of light attenuation.

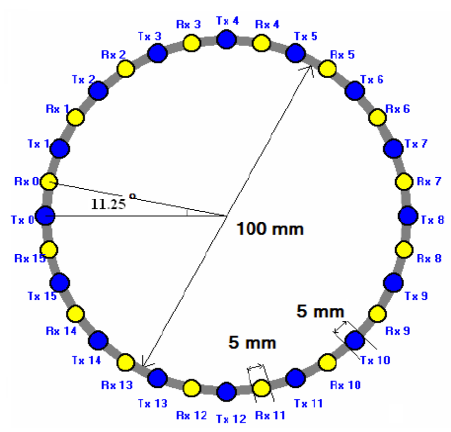


Figure 1 Sensors configuration for optical tomography system [6]

3.0 OPTICAL COHERENCE TOMOGRAPHY

Technology development in optical applications are used as a new approach to analyzing tissue samples and blood cells. Optical instrument approaches are used together in the medical field to the characteristics of light. This problem has attracted the attention of researchers who study the field of photonics as it shows potential for diagnostic technology in which optical coherence is implemented at lower resolutions down to micrometer size.

Moreover, there are studies showing that OCT is analogous to ultrasound imaging, but uses light rather than sound. Cross-sectional images are generated by measuring the echo time delay and intensity of visible light or light backscattered from the internal structure of the tissue [10]. Because the speed of light is very high, the echo time delay cannot be measured directly. Instead, it is necessary to use correlation or interferometer techniques. Technique measuring used base on concept the echo of light a low coherence interferometer. A low coherence interferometer is used to measure the reflection in fiber optic and optoelectronic devices [11–13].

OCT is a method of producing a high resolution cross-sectional image of the microstructure of living tissue [14]. This method has been used for almost a decade [14–18]. However, the concept of a white light interferometer led to the development of Optical Coherence Domain Reflectometry (OCDR), a one dimensional (1D) optical tracking technique [19, 20].

OCDR was originally developed for optical fiber cable network components; however, the implementation OCDR for medical applications for the treatment of the eye [12-14] and other biological tissues [21, 22] have been recognized. OCT is achieved by exploiting the short coherence light source bandwidth, enabling the OCT scanner to be used to obtain microscopic images of tissue structure at a depth beyond the reach of the bright-field and conventional confocal microscope. Imaging display is achieved with a depth of 2 cm have been shown to penetrate the lining tissues of the eye, for example in the study of the eye and frog embryos [23-25]. The internal structure of the skin with tissue scattered, OCT imaging can be done in blood vessels and other structures at a depth of 1-2 mm below the skin surface. [26], this is advantage when compared with ultrasound imaging [27], in addition to the relative simplicity and lower cost.

The term ‘optical coherence tomography’ contains the word ‘coherence’ because it uses a broadband light source. The light source in the OCT system is divided into two arms: the first is a sample arm containing the items observed and the other is a reference arm, which usually functions as a mirror. Coalition received and refracted light to the reference arm and the sample arm creates interference patterns, but only if the light from the two arms of the observations is at "the same" optical distance The reflection of light in the reference arm occurs when there are disruptions in the monitored sample elements consist of other materials. Different voltage values resulting in disruptions in the area compared to areas without interference. Sample areas that reflect a lot of light create a greater disturbance than areas that do not.

Any light that is outside the short coherence length will not interfere. Reflection profiles, known as A-scans, contain information about the dimensions of space and the location of the structure in the items of interest. A cross-sectional tomograph (B-scan) can be achieved by combining the depths from a series of axial scans (A-scan). The imaging face (C-scan) at the depth obtained may depend on the imaging machine used. The use of light with the delivery of broadband radiation at higher using super luminescent or also called as short laser pulses (femtosecond laser).

OCT can be used with the Time Domain (TD-OCT) and the Spectral Domain (SD-OCT) method [28]. In the category of SD-OCT, two formats are implemented, one based on a spectrometer and the other on a tunable laser. Each method has advantages and disadvantages depending on the use of the developed. The depth resolution achieved depends on the bandwidth of the optical source in TD-OCT and SB-OCT and on the tuning bandwidth in SS-OCT.

TD-OCT with light sources and optical interferometer consisting of mirrors and optical splitter is used to generate a reference beam. Microscopic optical interface is used to convey light from the splitter and the object to be examined, while the processing unit to analyze the resulting interference between the light beam and the reference beam. Direction of light waves from the splitter to the object and if there is a disruption of the actual length of wave path is blocked. The Optic Path Difference (OPD) in the interferometer is defined as the object path length. TD-OCT uses an optical source bandwidth and the processing unit uses a photo detector refer to Figure 2.

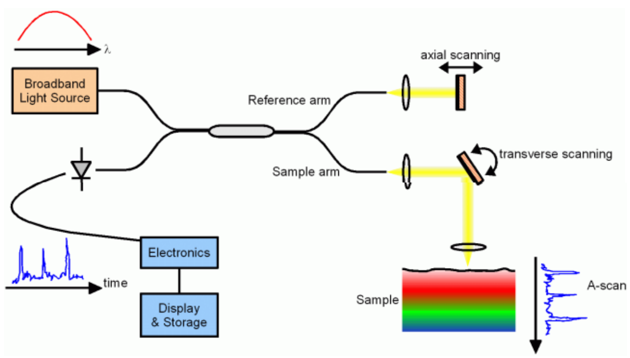


Figure 2 Time-Domain (TD-OCT) [29]

The principle of operation is based on the partial coherence interferometer, in which the photo detector detects differences WTO decision as long as the interruption is less than the coherence length of the broadband source [30]. So far, the configuration of the low-coherence interferometer is widely used in sensing. OCT scanner is designed to be able to scan the object aimed at the broad side of a scan on the object beam transverse to the arm [31].

SD-OCT refers to the interrogation of the spectrum at the output of the interferometer. A broadband optical source is used and the processing unit uses a spectrometer, which is usually constructed using a prism or diffraction grating and a photo detector linear array, using a charged coupled device (CCD) or a complementary linear camera with application metal oxide semiconductor (CMOS) [32].

Optical tomography sensor using the method of preparation of Organic Photovoltaic (OPV) laser sensor contribute to the source 302 nm - 650 nm, and the use of these devices can be categorized as a good signal. The methods used in this system are divided into two types, the first is parallel beam mode, where the sensors are arranged on a one-to-one basis, and the second type is a fan beam mode, where all transmitters operate at the same time next edge in wide angle projection beam wider, but this method provides critical delays during the scan performed [33].

Optical in parallel modes [34] is method in which the light source from single quartz halogen lamp used for imaging sized pipe diameter of 81 mm. Signal reception is carried out using PIN diodes; there are 16 sensor for full signal receiver and arranged in two projections . Tests are performed on the object through a vertical pipe with effects factor of scattering and diffraction scattering. Processing speed are a challenge to the system in which there is a collimating light slow to react to the object being monitor.

The resulting image is not parallel with the crossover time. Improvement method using two plane straight, linear with two orthogonal projection. Previously only 32 sets of sensors were used, but improvements have been achieved by using 38 transmitters to give a total of 76 units with a distance of 35 cm from the projection light source. Tests conducted by researchers found that the monitoring system for air bubble wrap bore of 1 mm – 10 mm with a speed capacity of 11 tons/min, but if large in size between 15 mm and 20 mm can affect the number of metrics 31/min [35].

LED and fan beam mode is the method of using an LED device as the light source while the receiver consists of a PIN photodiode using 16 pairs of sensor, but this method takes a long time and may not be appropriate for real-time measurements [36]. However, it is used to detect changes in the measurement range for small images. Air attenuation factors are considered zero. This factor is also used in solid particles. The reason is because the size and angle of projection geometry that absorbs light emitted during the process of scanning when light meets the surface of the emitting diode. [37].

Infrared LEDs and parallel beam mode are used by researchers using a transmitter LED of the TEMIC Semiconductor (TSUS4300) type, where the wavelength is 900–1000 nm and the peak wavelength is 950 nm [38]. A signal-receiver device such as an infrared phototransistor TEFT4300 is used [39] with dimensions 2 mm × 2 mm × 3 mm. Infrared LED fan beam mode is used as a transmitter and optical fibre consists of SFH 484-2, which has a wavelength of 880 nm [40]. The radius of the radiation angle is 16 inches. However, it was found that the tests carried out showed light absorption in the solid material and the effect of light diffraction with scattering being ignored. Number of sensors using 32 pairs arranged in the opposite direction.

The use of fiber optics for optical transmitters with insulated electrical input signals into modulated light for transmission over optical fibers. In addition, the light beam from the transmitter is received by the receiver via optical fibers [41].

The number of sensors is determined by the requirements of the size of the object to be detected to achieve high-resolution measurements in optical tomography. In addition, fiber optic sensor provides large bandwidth that allows measurements to be performed at high speed particle flow [42]. In the study, there were two types of sensor arrays for parallel projection and fan beam projection. For the sensor structure using the parallel projection method, the transmitter and receiver are matched with each other. For the fan beam projection method, there may be more than one recipient associated with single or multiple light sources. In switch mode fan beam method, multiplexing is used at the receiver signals corresponding to each source multiplexing and sensor configuration for the fan beam projections, the transmitter and receiver are arranged alternating with each other. This study applied the technique of multiple fan beam projection using fiber optic sensors in order to achieve a high data acquisition rate [43].

■4.0 LIGHT SOURCE FOR OPTICAL TOMOGRAPHY AND OPTICAL COHERENCE TOMOGRAPHY

Light can be used for absorption, diffraction, and reflection/refraction [44]. In OT, the use of light absorption in wave propagation is called attenuation. Objective criteria that are used to obtain the concentration profile of the solid and the gas flow rate during the process conveyor chute. Diffraction is usually used for particle size, and modelling of reflection and refraction will not focus on these parameters when used to solve topography [45].

An LED optic sensor element has been implemented as a light source and a PIN photodiode as the receiver element [46]. LED light source for the operation can be easily monitored as it cannot be seen by the human eye. LED susceptibility consider the elements to distinguish the signal from noise and effect to interfere signal reception. LED will be useful when less noise disturbance for different wavelengths sources. These advantages as the option for the purpose to apply light source in optical tomography.

For sensor receiver, two types of photo detectors are often used by researchers. The photodiode and phototransistor, photodiode is an option for fast response because the receiver can capture the true signal and implement noise filtering.

Some advantages are as follows: i) ultra-high power LED strips, ii) a wavelength of 650–1700 nm, iii) a low-cost package for fibre-based application which can operate for the free space, and iv) the costs for a Super Luminescent Diode (SLD), which is a combination of a diode laser coming from the power outlet and LED brightness with broad optical spectrum. Ideal functions to optimize wave diode laser amplifier with zero reflection from the end of the current channel.

In every SLD, propagating beams of spontaneous emission are amplified by the active area. And in terms of power output, the SLD performance can be described by a simple model that does not take into account the impact of the spectrum and assumes a uniform distribution of the carrier density inside of the SLD. Describing the zero spectrum, several parameters describing a SLD spectrum: i) the width of the spectrum, which is always specified in the full width at half maximum (FWHM) and determines what is called the coherence length, and ii) the modulation spectrum is called Fabry-Perot parasitic modulation with non-zero terms of reference for SLD.

Most LDS emit in a single transverse mode. However, as the tilt of the waveguide is one of the most common approaches to reduce reflection of the production, this SLD can be described as a laser diode [47]. An example is shown in Figure 3.

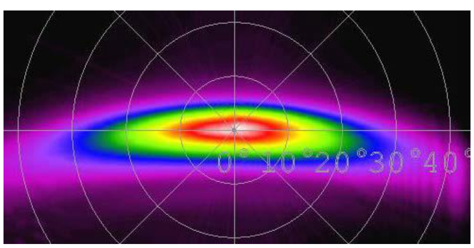


Figure 3 As above field SLD a laser diode [48]

Single spatial mode emission allows high coupling efficiency to a single-mode fibre: 20–40% coupling efficiency may be obtained by the use of a spherical micro-lens on the fibre end, and it may be increased up to 60–70% by the use of a cylindrical micro-lens.

More applications this component consists of strain, pressure and current and the same function to apply in medical field. In addition, fibre optic channel monitors are used. At the same time navigation systems also use this method in air, space, and sea or land surfaces. The differences between penetration and resolution are shown in Table 1.

Table 1 Comparison of penetration versus resolution in tomography systems [49]

Item	OCT	Ultrasound	MRI	Fluoroscopy
Resolution (μm)	1–15	80–120	80–300	100–200
Probe size (μm)	140	700	NA	NA
Ionizing radiation	No	No	No	Yes

The principles of SLD are as follows:

i) Combination of laser diodes
ii) Combination allows high optical gain in semiconductor laser material
iii) Wide optical spectrum area
iv) High optical gain and active region of high sensitivity to external optical SLD feedback; for example 30 dB is 1% feedback, which means there are 10 times more photons
v) Available for high temperature at the level of 680 nm, 1300 nm, and 1550 nm bands.
vi) SLD polarization strongly on structure; for example the TE/TM polarization ratio is over 50:1
vii) The SLD noise spectrum is white, for example 30 dB and 100 kHz starting at an output power of 3–5 mW.
viii) Modulation SLD is intended as a source of light and able to work up to 100 kHz without problems

■5.0 INTERFEROMETER IN OPTICAL TOMOGRAPHY

The Mach-Zehnder interferometer has two input ports and two output ports. The light is split into the two arms of the input coupler of the interferometer, and they are later recombined in the output coupler of the interferometer. The optical length of the two arms is unequal, so the plane corresponds to the delay. The relative phase of the light in the two input ports of the output coupler is therefore a function of wavelength.

The Mach Zehnder interferometer was developed by Ludwig Mach and Ludwig Zehnder. The diagram shown in Figure 4 uses two beams separately and recombined, and thus there will be two outputs depending on i) optical long arms, ii) the wavelength (optical frequency). The length of this route can be adjusted [50].

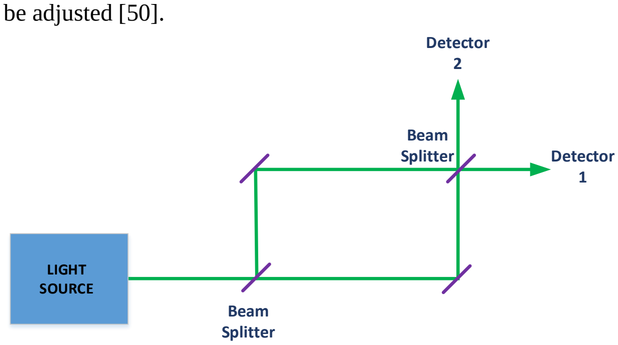


Figure 4 March Zehuder Interferometer [50]

The Fabry–Perot interferometer consists of two parallel mirrors that allow light with high reflective, as shown in Figure 5. This can happen because the resonance is very sharp. This method showed that high levels of redirection can only be used at the appropriate frequency. In terms of the resolution is high and the wavelength. Some authentication methods are implemented by Fizeau interferometer used of a mirror is a reflection by its optic component. Light is used to influence the beam splitter angle [51].

Figure 5 Fabry–Parot interferometer [51]

The Michelson interferometer as shown in Figur 6 [52], developed by Albert A. Michelson, using a single beam splitter and beam scanning in return for some combination process by adjusting the mirror. Example diagram below is perpendicular to the incident light output while what is produced back to the source. Some combination of the beam can occur in different locations in the beam splitter. In addition, the use of retro reflectors are used if non-zero path difference is realized in a noise monitoring. A recombinant beam can occur at different locations on the beam splitter. In addition, the use of a retro reflector is applied if the non-zero path difference is realized in the noise monitoring.

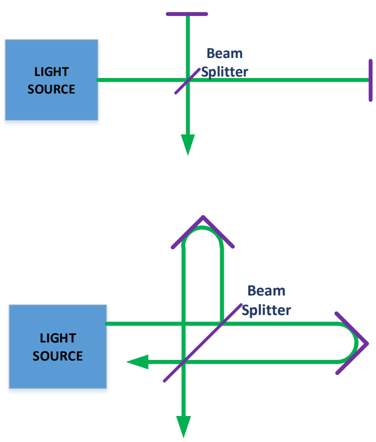


Figure 6 Michelson interferometer [52]

A common path interferometer is the common methods using the beam but varies in terms of polarization. This method can serve as a sensitive detector of birefringence.

An alternative system to the one above was introduced which differed in one or two key areas: i) the use of a linear optical interferometer coupled with a laser head (either internally or externally); the laser head is then mounted directly on the engine; and ii) use of electronic devices at distant targets (not the interferometer), to measure pitch, yaw, and straightness errors, and some offer simultaneous five-dimensional (5D) measurements. This application is available on the machine, which requires a reference to the process of manufacture of machinery for implementation.

5.1 Linear Measurements

There are benefits of using a tripod-mounted laser, optical interferometer only remotely mounted directly on the engine and the heat generated by the laser emitted from the optical interferometer. The reference arm of the interferometer with linear forms a reference point from which all movement is measured by the machine. Any change in the position or in the long arm of the interferometer reference, caused by thermal expansion or contraction, will reduce the accuracy of these measurements.

To ensure the changes to an absolute minimum, the Renishaw system follows the principles of metrology by keeping the heat from the laser source from the optical measurements.

5.2 Interferometer Advantages

The industry uses linear interferometer, and a variety of resolutions to facilitate alignment. A photo detector produces an analogue output which varies according to where the laser beams onto the target. The interferometer angle offers excellent resolution and linearity. Interferometer optical alignment is easy and quick corner adjustments. Renishaw interferometer using a detection angle with the substance consisting of helium neon laser with a wavelength that is stable, in combination optical lever arm, made of two solid glass retro reflector mounted in a compact aluminum housing, to ensure accuracy and long-term performance of the system. For mass Renishaw minimum reflector assembly (including mounting blocks and columns) is about 450 g. Mass sensor head contains a linear retro-reflector, the target adjustment, electronic, mechanical and electronics to follow the cable can be 800 g.

Moreover, in the application of this system there are no trailing cables. The interferometer and optical corner reflector mounted on the machine do not need wires or signal cables. For example, if the machine was involved in the movement of the arm, care should be taken to ensure that the cable is not interrupted or trail that can cause damage or cause measurement error. This method can also be seen as reducing the error of the instability of the laser. The interferometer measures the angle of relative movement between the interferometer and retro-reflectors, and is largely insensitive to small changes in the direction of the laser beam pointer from the head.

However, the same electronic target system is sensitive to changes in the direction of the laser beam as it is to pitch and y axis. Light Insensitivity to ambient by quad cells or PSD (position sensitive detector) technology provides an output signal which indicates the intensity of all directions. If the ambient light reaches the target, it will add to the light from the laser beam and switch to the center of intensity. It is possible to reject ambient light variations either by modulating the laser resources or by using special optical filters that allow only the laser light through. However, if the same laser is used for a simultaneous linear interferometer, the beam modulation is difficult. Also a high quality optical band-pass filter which allows only the laser through and blocks all other wavelengths. This results in a trade-off between cost and performance, which often leads to sacrificing of the accuracy of the system. The interferometer is sensitive to light having a wavelength of almost same the laser beam, because this is the only light that can interfere with optical beams at a detector to respond. In addition Renishaw interferometer systems contain a special differential photodiode detector system that prevents ambient light causing electricity offset and sub-fringe interpolation errors.

Lower sensitivity to stray laser light is reflected. Reflections from a variety of internal and external optical surfaces in the system can generate a laser beam wander. Usually anti-reflection-coated optical surfaces the intensity of this beam. However, if the beam reaching the detector system is weak, it will affect the measurement. In the case of an interferometer system it is very difficult to cause measurement error with stray light, as it should be aligned almost perfectly parallel to the main beam. Even if this does not happen, the worst-case error of 0.5% for the intensity of stray light (a typical reflection of the anti-reflection coated surface), is about 1/100th of a fringe, (equivalent to 0:03 seconds of arc in angle measurement mode). In the case of an electronic target, the effect is much more severe and depends on both the intensity and angle of the beam wander into the lens and the target assembly. For the measurement of the angle range, the Renishaw interferometer angle measurement provides a range of ± 10°, while maintaining excellent resolution (0.01 arc second) and linearity (arcsine corrected).

■6.0 CONCLUSION

Due to the need and demand for innovation in the field of photonics, the development of optical tomography (OT) has grown rapidly in less than 10 years. Development eventually led to the widespread use of optical coherence tomography (OCT) in the medical sector as a diagnostic technique and in industry, where it can assist in an efficient monitoring process, and thus innovation depends on the ability of researchers to solve some problems to upgrade it to a more efficient system, which currently limits the performance of OCT systems. Stronger and wider band light sources, novel interferometer configurations, faster scanning, and high-contrast imaging modes are continuous developments that could lead to the solution of these problems. More effort is needed to put the theory of optical coherence tomography of biological tissue on a much stronger foundation. As other discuss describe the medical imaging modality, the combination of a solid theoretical analysis and new technology offers the best hope for the future.

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References

[1] Norhafizah Ramli & Siti Syazalina Mohd Sobani. 2013. Four Projections CMOS Linear Image Sensor Tomographic Image Reconstruction. *Jurnal Teknologi (Sciences & Engineering)*. 61(2): 19–83. ww.jurnalteknologi.utm.my. eISSN 2180–3722.

[2] Cutler M. 1929. Transillumination As An Aid In The Diagnosis Of Breast Lesions. *Surg Gynecol Obstet.* 48: 721.

[3] Olhsson B, Gunderson J, Nilsson D. M. 1980. Diaphanography: A Method For Evalution Of The Female Breast. *World J Surg.* 4: 701–7.

[4] Carlsen E. N. 1982. Transillumination Light Scanning. *Diag Imag.* 3: 658–664.

[5] Green, R. G., Horbury, N. M., Abdul Rahim, R., Dickin, F. J., Naylor, B. D. and Pridmore, T. P. 1995. Optical Fibre Sensors For Process Tomography. *Meas. Sci. Technol.* 6: 1699–1704.

[6] M. Fadzli Abdul Shaib, Ruzairi Abdul Rahim, Siti Zarina M. Muji, Naizatul Shima, Mohd Zikrillah Zawahir. 2013. Comparison Between Two Different Types of Microcontroller in Developing Optical Tomography Controller Unit. 64(5): 13–17. www.jurnalteknologi.utm.my. eISSN 2180–3722.

[7] C. Yan, J. Zhong, Y. Liao, S. Lai, M. Zhang, and D. Gao. 2005. Design Of An Applied Optical Fiber Process Tomography System. *Sensors And Actuators.* 104: 324–331.

[8] S. Z. M. Muji. 2011. Optical Tomography: A Review On Sensor Array, Projection Arrangement and Image Reconstruction Algorithm. International Journal of Innovative Computing. *Information and Control.* 7(7): 1–17.

[9] Huang D., Swanson E. A., Lin, C. P., Schuman, J. S., Stinson, W. G., Chang, W., Hee, M. R., Flotte, T., Gregory, K., Puliafito, C. A., Fujimoto J. G. 1991. Optical Coherence Tomography. *Science.* 254: 1178–1181.

[10] Fujimoto J. G., Brezinski M. E., Tearney G. J., Boppart S. A., Bouma B., Hee M. R., Southern J. F., Swanson E. A. 1995. Optical Biopsy And Imaging Using Optical Coherence Tomography. *Nature Med.* 1: 970–972

[11] Brezinski, M. E., Fujimoto, J. G. 1999. Optical Coherence Tomography: High Resolution Imaging in Nontransparent Tissue. *IEEE J. Sel. Topics Quant. Electron.* 5(4): 1185–1192.

[12] Fujimoto, J. G., Pitris, C., Boppart, S. A., Brezinski, M. E. Optical Coherence Tomography: An Emerging Technology for Biomedical Imaging and Optical Biopsy. *Neoplasia* 2: 9–25.

[13] Takada K., Yokohama I., Chida K., Noda J. 1987. New Measurement System For Fault Location In Optical Waveguide Devices Based On An Interferometric Tchnique. *Appl. Opt.* 26: 1603–1608.

[14] Youngquist, R. C., Carr, S., Davies, D. E. N. 1987. Optical Coherence-Domain Reflectometry: A New Optical Evaluation Technique. *Opt. Lett.* 12: 158–160.

[15] Gilgen, H. H., Novak, R. P., Salathe, R. P., Hodel, W., Beaud, P. 1989. Submillimeter Optical Reflectometry. *IEEE J. Lightwave Technol*. 7: 1225–1233.

[16] D. Huang, E. A. Swanson, C. P. Lin, J. S. Schuman, W. G. Stinson, W. Chang, M. R. Hee, T. Flotte, K. Gregory, C. A. Puliafito, and J.G. Fujimoto. 1991. Optical Coherence Tomography. *Science.* 254: 1178–1181.

[17] A. F. Fercher, C. K. Hitzenberger, W. Drexler, G. Kamp, and H. Sattmann,. 1993. In Vivo Optical Coherence Tomography. *Ophthalmol*. 116: 113–114.

[18] J. M. Schmitt, A. Kn¨uttel, M. Yadlowsky, R. F. Bonner. 1994. Opticalcoherence Tomography Of A Dense Tissue: Statistics Of Attenuation And Backscattering. *Phys. Med. Biol.* 42: 1427–1439.

[19] J. M. Schmitt, M. Yadlowsky, R. F. Bonner. 1995. Subsurface Imaging If Living Skin With Optical Coherence Tomography. *Dermatol.* 191: 93–98.

[20] J. G. Fujimoto., M. E. Brezinski., G. J. Tearney., S. A. Boppart., B. E. Bouma., M. R. Hee., J. F. Southern, and E. A. Swanson. 1995. Optical Biopsy And Imaging Using Optical Coherence Tomography. *Nature Med.* 1: 970–972.

[21] R. C. Youngquist., S. Carr., D. E. N. Davies. 1987. Optical Coherence Domain Reflectometry: A New Optical Evaluation Technique. *Opt. Lett.* 12: 158–160.

[22] K. Takada, I. Yokohama, K. Chida, and J. Noda,. 1987. New Measurement System For Fault Location In Optical Waveguide Devices Based On Interferometric Technique. *Appl. Opt.* 26: 1603–1606.

[23] W. Clivaz, F. Marquis-Weible, R. P. Salathe, R. P. Novak, and H. H. Gilgen. 1992. High Resolution Reflectometry In Biological Tissue. *Opt. Lett.* 17: 4–6.

[24] J. M. Schmitt, A. Kn¨uttel, and R. F. Bonner,. 1993. Measurement Of Optical Properties Of Biological Tissues By Low Coherence Reflectometry. *Appl. Opt.* 32: 6032–6042.

[25] M. R. Hee, J. A. Izatt, E. A. Swanson, D. Huang, C. P. Lin, J. S. Schuman, C. A. Puliafito, and J. G. Fujimoto. 1995. Optical Coherence Tomography Of The Human Retina. *Arch. Ophthalmol.* 113: 326–332.

[26] S. A. Boppart, M. E. Brezinsk, B. E. Boump, G. J. Tearney, and J. G. Fujimoto. 1996. Investigation Of Developing Embryonic Morphology Using Optical Coherence Tomography. *Dev. Biol.* 177: 54–64.

[27] Y. Pan, E. Lankenau, J. Welzel, R. Birngruber, and R. Engelhardt. 1996. Optical Coherence Gated Imaging Of Biological Tissues. *IEEE J. Select. Topics Quantum Electron.* 2: 1029–1034.

[28] C. Passmann and H. Ermert. 1996. A 100 MHz Ultrasound Imaging System For Dermatologic And Ophthalmologic Diagnostics. *IEEE Trans. Ultrason. Ferroelect., Freq. Contr.* 43: 545–552.

[29] J. M. Schmitt. 1999. Optical Coherence Tomography: A Review. *IEEE Journal of Selected Topic in Quantum Electronic.* 5(4): 1205–1215.

[30] Drexler, W. & Fujimoto, J. G. 2008. State Of The Art Retinal Optical Coherence Tomography. *Progress In Retinal And Eye Research.* 27: 45–88.

[31] Huang, D., Swanson, E. A., Lin, C. P. 1991. Optical Coherence Tomography. *Science.* 254: 1178–1181.

[32] Smith, L. M. Dobson, C. C. 1981. Absolute Displacement Measurements Using Modulation Of The Spectrum Of White Light In A Michelson Interferometer. *Appl. Opt.* 28(15): 3339–3342.

[33] D. Huang, E. A. Swanson, C. P. Lin, J. S. Schuman, W. G. Stinson, W. Chang, M. R. Hee, T. Flotte, K. Gregory, C. A. Puliafito, J. G. Fujimoto. 1991. Optical Coherence Tomography. *Science.* 254: 1178–1181.

[34] Z. Mohd. Muji, R. Abdul Rahim and M. Morsin. 2009. Criteria For Sensor Selection In Optical Tomography. IEEE Symposium On

Industrial Electronics And Applications. Best Western Premier Seri Pacific Hotel, Kuala Lumpur.

[35] R. G. Green, R. Abdul Rahim, K. Evans, F. J. Dickin, B. D. Naylor, and T. P. Pridmore. 1998. Concentration Profiles In A Gravity Chute Conveyor By Optical Tomography Measurement. *Powder Technology.* 95(1): 49–54.

[36] S. Ibrahim, R. G. Green, K. Dutton, and R. Abdul Rahim. 2002. Lensed Optical Fiber Sensors For On Line Measurement Of Flow. *ISA Transactions*. 41(1): 13–8.

[37] N. Zeng, S. Lai and Y. Liao. 2001. Optical Tomography For Two Phase Measurement. *Proc. of SPIE The International Society for Optical Engineering*. 4448: 341–347.

[38] P. Dugdale, R. G. Green, A. J. Hartley, R. G. Jackson and J. Laundauro. 1994. Characterization Of Single Bubles By An optical Tomography System. European Concerted Action on Process Tomography.

[39] R. Abdul Rahim, K. T. Chiam, M. J. Pusppanathan. Y. S. L. Susiapan. 2009. Embedded System Based Optical Tomography: The Concentration Pro_Le. *Sensor Review*. 29(1): 54–62.

[40] S. Ibrahim, R. G. Green, K. Dutton, K. Evans, R. A. Rahim, and A. Goude. 1999. Optical Sensor Configurations For Process Tomography. *Meas. Sci. Technol.* 10: 1079–1086.

[41] R. A. Rahim, P. J. Fea, C. K. San, and M. H. Fazalul Rahiman. 2006. Optical Tomography: Infrared Tomography Sensor Configuration Using 4 Parallel Beam Projections. *Sensors & Transducers.* 72(10): 761–768.

[42] R. A. Rahim, L. C. Leong, K. S. Chan, S. Sulaiman, J. F. Pang. 2005. Tomographic Imaging: Multiple Fan Beam Projection Technique Using Optical Fibre Sensors. Computers, Communications, & Signal Processing with Special Track on Biomedical Engineering. 1st International Conference on 14–16 Nov. 2005: 115–119.

[43] Green, R. G. 1998. Concentration Profiles In A Gravity Chute Conveyor by Optical Tomography Measurement. *Journal Powder Technology*. 95: 49–54.

[44] Investigating Multiple Fan Beam Projection Technique Using Optical Fibre Sensor In Process Tomography, Ruzairi Abdul Rahim, Leong Lai Chen, Chan Kok San & Mohd. Hafiz Fazalul Rahiman. 2007. *Jurnal Teknologi*. Universiti Teknologi Malaysia. Skudai. Malaysia 47: 61–70.

[45] R. G. Jackson. 1995. *The Development of Optical Systems for Process Imaging in Process Tomography*. Butterworth Heinemann.

[46] R. Abdul Rahim and K. S. Chan. 2004. Optical Tomography System for Process Measurement using LED As A Light Source. *Optical Engineering*. 43: 1251–1257.

[47] Vladimir Shidlovski. 2004. Superluminescent Diodes: Short Overview Of Device Operation Principles And Performance Parameters. Superlum Diodes Ltd. Carrigtwohill, Co. Cork, Ireland. 7–8.

[48] L. H. Hong., A. Yahaya., Y. Munajat. 2014. Determination of Optical Path Difference of White Light Fibre Interferometer Using Peak Tracking Method. *Jurnal Teknologi*. Department of Physics, Faculty of Science, Universiti Teknologi Malaysia. 71(5): 79–82.

[49] Tearney, G. J., Brezinski, M. E., Southern, J. F., Bouma, B. E., Boppart, S. A., Fujimoto J. G. 1997. Optical Biopsy In Human Gastrointestinal Tissue Using Optical Coherence Tomography. *Am J Gastroenterol.* 92: 1800–4

[50] K. P. Zetie, S. F. Adams, R. M. Tocknell. 2000. How Does A Mach-Zehnder Interferometer Work. *Physics Dept. Westminter School. London SW1 3PB.* UK. 38(1): 46–48.

[51] Lipson, S. G., Lipson, H., Tannhauser, D. S. 1995. *Optical Physics*. 3rd ed. London: Cambridge U.P. 248. ISBN 0-521-06926-2.