Tomography System Towards the Industrial Revolution 4.0

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ABSTRACT

The world developed rapidly to provide better standard of living to the human being. Industrial revolution 4.0 promising in great revenue, investment and technological advancement to the society and various sectors. This paper presents an overview of tomography system towards the industrial revolution 4.0. Tomography is essentially a technique for showing an image representation through solid objects, such as a pipeline or the human body, in the two-dimensional and three-dimensional cross sections. Several tomography sensors, including optical tomography systems, ultrasonic tomography systems and an electrical tomography system, are discussed in terms of their hardware and image reconstruction. To provide a clear view of tomography system, a few examples of tomography system application in medical and process industries are discussed.

Keywords: tomography, image reconstruction, applications

1. Introduction

Industrial Revolution 4.0 or commonly known as Industry 4.0 has improve the manufacturing efficiency nowadays by investing in the new tools and technology. This has enhanced the human well-being and by revolutionizing the entire business operates and grows [1]. Since 1800s, manufacturing has evolved and still continue until today. The first industrial revolution occurred within the late 1700s to early 1800s [2]. The use of steam-powered engines is optimized by manually labor performed by peopled and sometimes assisted by animals. The introduction of electricity and the used of steel indicate the second phase of industrial revolution. This happened at the early of 20th century [3]. During this time, the assembly line concepts was introduced to produce mass production concept as a technique to increase the productivity. Eventually, electronic and computing technology began to emerge with manufacturing process starting in the late of 1950s [4].

The third industrial revolution started to shift the mechanical technology into the digitalized and automation framework [5]. The manufacturing experience automation, more complexation and sustainable production so that people could always efficiently and persistently operate the machine. The more comprehensively, interlinked and holistic approach was introduced in the past few decades as the Industry 4.0 take places. Those emerging of technology are emphasis to whole new level with the integration through the Internet of Things (IoT), cyberphysical systems (CPS), real-time data access, artificial intelligence (AI) and big data analysis. The existing machine is then converted into self-aware and self-learning machines to boost their overall efficiency and maintenance management. This will eventually allow better cooperation between the physical and digital component, product and people across the place and time.

One of the rapid technologies developed in Industry 4.0 is the signal processing. Signal processing is one of the engineering approaches to model and interpret data representations received of physical events [6]. Such signals like images, sounds and other scientific measurement are required for data analyzing, synthesizing and modifying. This method has empowered the ability to communicate between the biotechnology and social interaction [6]. One of the examples of signal processing is the tomography system. Tomography system is commonly known for viewing the 2D or 3D images in a function of time. Figure 1 **Error! Reference source not found.** shows the basic block diagram for tomography system [7].

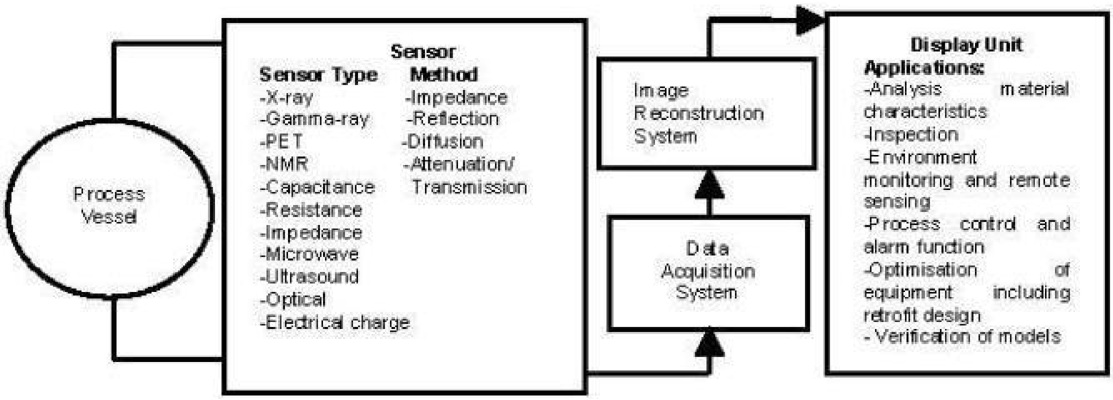

Figure 1. Block diagram of typical tomography system [7]

Huge application of tomography was applied in the medical industry since in 1950. For instance, the computed tomography (CT or CAT) is the composition of computer and X-rays to display pictures of the bones, other organs and body tissues [8]. Compared to a regular X-ray, this method shows more detailed in terms of the image constructed. Such as in industry, monitoring of the pipeline to avoid splitting of welding defects, cavitation degradation, media corrosion and material deterioration after a certain period of time may contribute to leakage and explosion accident [9]. Ultrasonic tomography was introduced to deal with this issue by giving high attenuation of ultrasonic energy to the steel pipes implementation. For multiphase flow industry, tomography system is the best approach for the application the requiring a non-intrusive and non-invasive monitoring systems [10].

2. Types of Tomography System

There are various types of tomography method has been existing more than 10 years ago such as ultrasonic tomography, capacitance tomography, optical tomography, impedance tomography, and resistance tomography. This tomography method also is developed because it is non- invasive and nonintrusive monitoring so that it significantly will help the new research to study and discover new knowledge about internal characteristics of matter such as to measure the velocity, diameter, distance, texture, mass flow rate, counter, shape and concentration [11]. Figure 2 shows the basic block diagram of a tomography system.

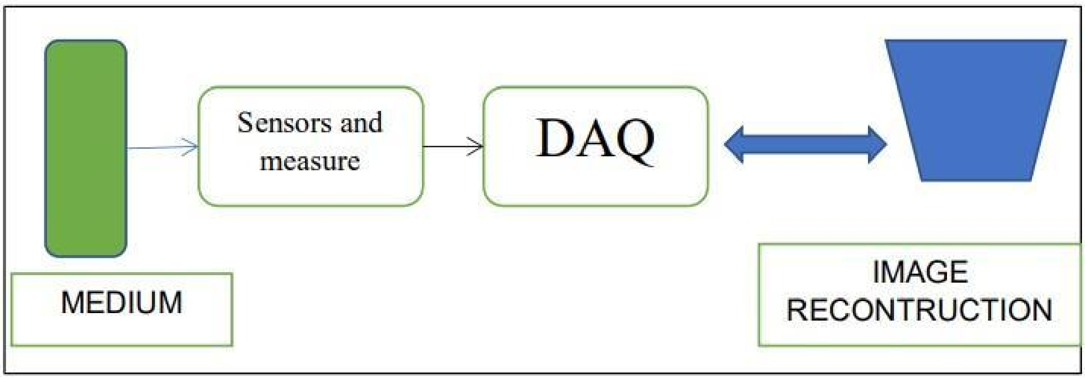

Figure 2. Basic block diagram of a tomography system [12]

Optical tomography approaches are non-intrusive in practice and secure since direct physical interaction with the flow is not required by the transducer. The system has high productivity and could increase production in the chemical industries. Optical techniques can produce high-resolution images for activities that treat transparent substances and other parts where the optical penetration is feasible. The optical tomography approach is competent to accomplish on-line measurements with its direct optical transmitter-receiver pairs [13].

Optical tomography reconstructs the image on the basis of optical radiation, sending a light beam from one edge and receiving light beam from another edge. By using various optical sensor types, such as lasers, linear CCDs, LEDs, etc., optical radiation can be produced. The drawback of optical tomography, however, refers to the restriction of its optical surface where it is not possible to put the sensors too close to each other in order to prevent reflection and to simple detect the image between the optical sensor areas [14].

As the sensing field is based on the calculation of the attenuation or absorption of light sources, the optical tomography device is called a hard-field sensor. Typically, the key principle of optical tomography is to analyze the structure and nature of objects by analyzing the strength of light after entering the target. Compared to other soft-field sensors, this optical tomography device has several benefits, which include being resistant to electrical noise or interference and also high resolution. Because of the speed of light, a tiny wavelength can have high resolution and insignificant response time as the speed of light is [15].

In tomography system, ultrasonic tomography (UT) has the potential for image reconstruction since it has the most effective sensing capability in differentiating the elasticity and the density of a certain object such as the liquid flows/bubble imaging. The ultrasonic sensor has massive advantages in tomography systems such as [16]. it is a non-invasive system where the sensor does not have direct contact to the fluid. It does not use any radioactive material which are safer compared to other type of tomography (positron emission tomography). In addition, it gives a quick response within a fraction of a second. Lastly, the transducers need only low energy levels to excite and this does not harm the plant or the materials being used. However, some of the limitation found in this acoustic characteristic is that, it can only effectively travel when there is a medium. Next in a multiphase flow application, high level of noise arise when the particle hit the flow pipe and thus researcher ought to take it into account during the analyzation process.

UT systems consist of the hardware and software parts [17] as shown in Figure 2. On one side of the pipe, the ultrasonic sensor transmitter that eventually connected to the amplifier circuit will convert the electrical energy signals into the ultrasonic waves. Then, the ultrasonic sensor receiver received the ultrasonic waves and transform it into the electrical signal. Figure 3 is the structure of the receiver part is consisting of the band pass, filters, lownoise amplifier and some cost data [18].

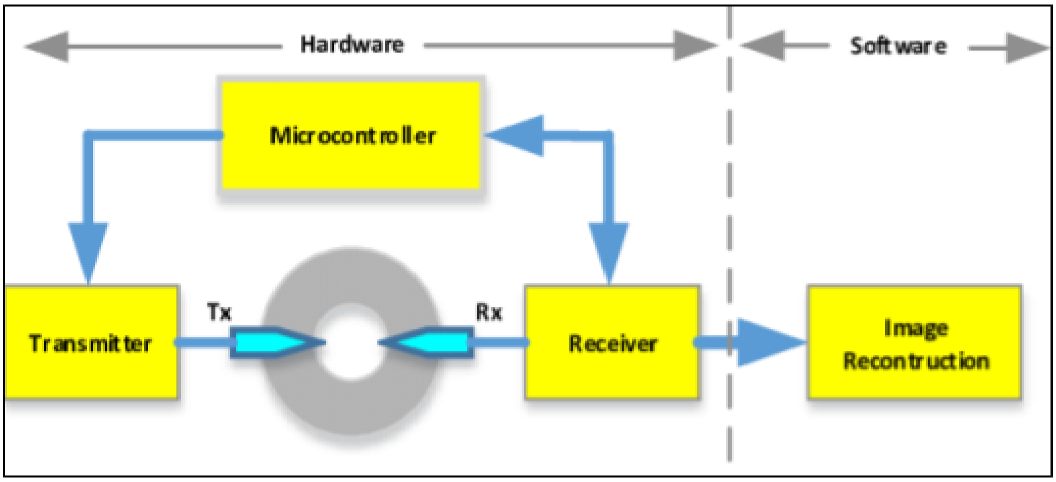

Figure 3. General block diagram of an ultrasonic tomography system [18]

The software part for image reconstruction in the ultrasonic tomography system is usually rely on the algorithm choose by the researches. The popular method used for the image reconstruction is the back-projection algorithm method. Initially, this method is introduced for use in X-ray tomography [16]. Back projection algorithm method provides low cost computational that eventually made it as the chosen method by the researchers. The back projection is solved once the solution for the forward problem obtained in this algorithm.

Liu et al [19] has addressed a circular scanning method used for imaging the location of breast cancer using the Piezoelectric Micromachined Ultrasonic Transducer (PMUT). The characteristic of breast cancer which has higher density eventually will distinguish the sound speed from the other elastic properties in the breast model [20]. Figure 4 below shows the location of masses that located in the centre of breast model for size 5.0 cm, 5.1 cm and 4.9 cm respectively.

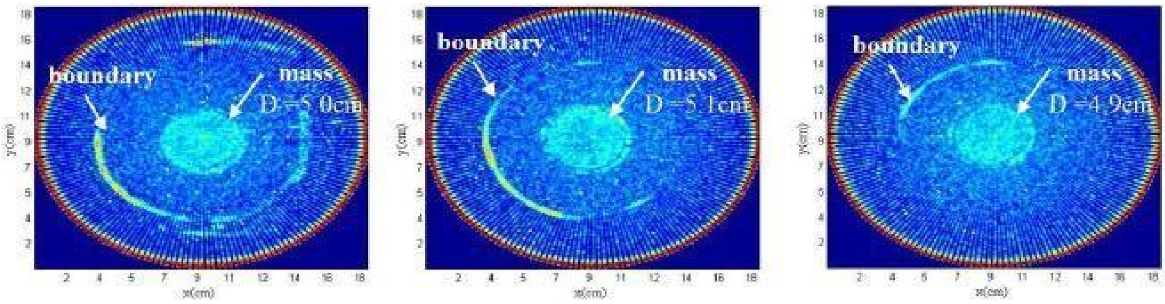

Figure 4. Ultrasonic tomography of breast model using the ring system [19]

Electrical tomography has been used widely among the other type of tomography due to its advantages such as; low cost consumption, non-invasive capability non emitting radiation photon compared to some other type of tomography. There are a few types of electrical process tomography and some of the example are Electrical Resistance Tomography (ERT), Electrical Capacitance Tomography (ECT) and Electrical Impedance Tomography (EIT). In ERT process application, the EIT is the measurement of impedance that comprise of the imaginary part which are the reactance and the real part which referred to the resistance. The dominants properties in EIT are the real part. The ECT process sense the distribution of permittivity at non-conductive continuous process meanwhile the EIT implemented for a conductive continuous type of process. Basically, the Electrical Tomography system basically of electrode that function both as electrode and sensor. When current is injected into the electrode, subsequentially another side of electrode will measure the voltages value received. Until all the independent measurement completed to measure the voltage, the process is repetitive for the following electrode's couple. The difference in these three types of electrical tomography is the type of sensor used.

3. Application of Tomography System

Tomography have biggest contribution in medical field through its ability to obtain the information from human body that is valuable in clinical applications [21]. Tomography method such as X-ray, the Positron Emission Tomography (PET), optical coherence tomography (OCT) and Magnetic Resonance Imaging (MRI) are some of method used to visualize the tissue structure and detect the cancerous constituent in human body.

The widely used of tomography operation in medical sector is X-rays. In essentially, X-rays are kind of electromagnetic energy that is performed by particles known as photons [8]. The energy level of individual photons, also known as the wavelength of radiation, is the difference between X-rays and visible light rays. A clear detectable wavelength is susceptible to the human eye, but not to higher energy wavelengths that are shorter. As shown in Figure 5, an X-ray machine is consisting of a pair of electrodes in a glass vacuum composed of a cathode and an anode. A cathode is a heated filament. Heat sputters electrons off the surface of filaments.

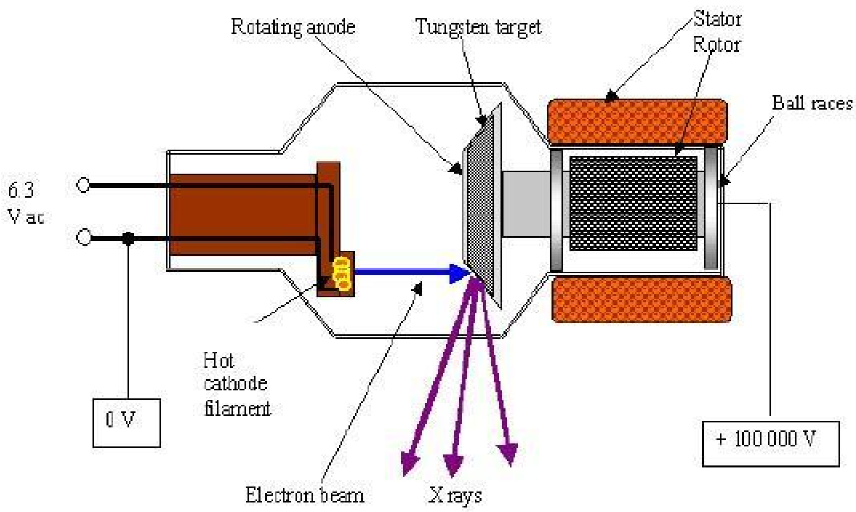

Figure 5.Building an X-ray glass vacuum tube [8]

To analyse blood vessels or other elements of the circulatory system the contrast medium will be infused into the patient's bloodstream. In combination with a fluoroscope, a contrast medium is also used. Whereas, a moving image of the X-ray is produced as the x-rays move through the body to a fluorescent screen in fluoroscopy. For the detection of the path of contrast media through the body, doctors can use fluoroscopy. Doctors may use the CT scanning to capture the moving X-ray images on film which combine processes in a digital form. The images are generated as a 2D model form and radiography [8] to display the information observed. Figure 6 shows the radiography X-ray picture of the chest, where the white image is shown showing the compact bone structure, the dark areas represent less dense structural elements that allow the passage of radiation.

Figure 6. A typical X-ray radiograph of the chest, in which the regions of bone are reflected in white [4]

The most prevalent disease in women worldwide is breast cancer. Thus, it is vital to have early detection approach on this issue. Liu et al. [19] address a modal to visualize the breast cancer imaging by using ultrasound computer tomography (USCT). The USCT method is radiation-free, painless and acceptable for all types of breasts compared to the mammography, the magnetic resonance imaging and hand-held ultrasound that result in dangerous radiation and painful compression to the examinee. Figure 7 and 8 below shows the experimental setup of this operation and the ultrasound tomography transducer acquisition setup respectively.

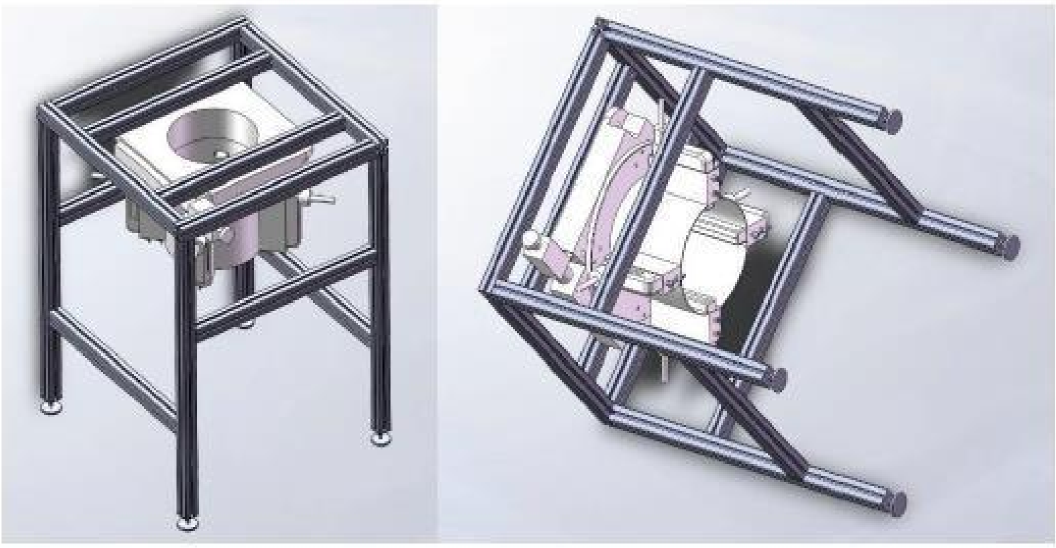

Figure 7. Experimental setup for the 3D ultrasound imaging ring system [19]

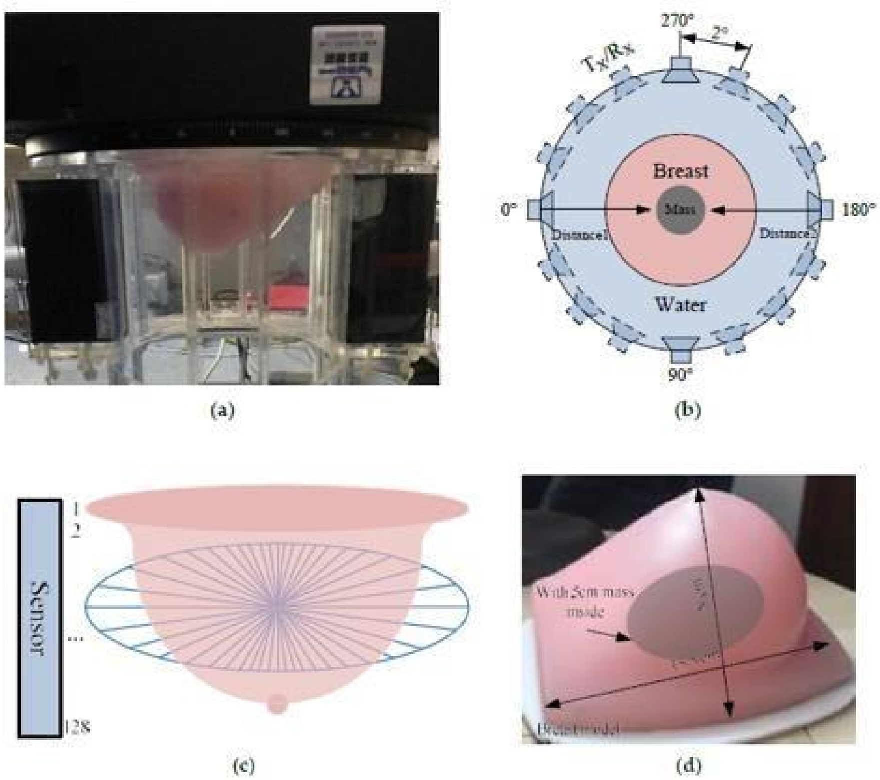

Figure 8. Ultrasound tomography transducer acquisition setup. (a) Placement of breast in the ring; (**b**) Transducer ring configuration platform; (**c**) Slice maps of ultrasound tomography imaging;(**d**) Breast Model [19]

Tomography system also widely used in process industries. For example, ultrasonic tomography is used in metal industries. After a certain period of time, cavitation erosion, media corrosion, welding defects cracking, substances leakage and explosion crashes might arise due to the degradation of materials [22]. In petrochemical industry, an issue potency results due to the defects and corrosion in pipeline and storage tank that will result in financial lost in terms of product losses, downtime in output, initiatives and fines for environmental cleanup [23]. Therefore, a monitoring operation ought to be implemented to reduce those risk that might harm to the human and environment. Tomography is one of the popular techniques used for monitoring process due to it low cost and simple circuit construction.

Hong et al [7] has review the application of various kind of sensor in tomography system for the metal industry. The steel pipes have worst internal reflections inside sealed pipes, besides its high ultrasonic energy attenuation and high bulk wave influence [7]. By using ultrasonic sensor, the ultrasound was examined by using two types of mode which are the longitudinal and shear waves. The ultrasonic wave attenuated due to a phenomenon such as scattering and diffusion in steel. The difference in velocity received by the ultrasonic sensor will then determine the different condition of material (crack, defect). The other method is by using the X-ray computed tomography (CT) to detect any crack and corrosion of steel pipe.

Ramsey et al. [24] inspect and control the quality of metal AM parts using this approach. The measurement includes the coordinate for dimensional metrology with inspecting the complex geometry and volume defects. Figures 9 and 10 below are the scans reveal the external and internal features of metal and the example of micro-CT technology in capturing the volume inside incandescent bulb, a fluorescent light bulb and an LED bulb respectively. Both picture proven better reconstruction of CT method to see the internal part of metal.

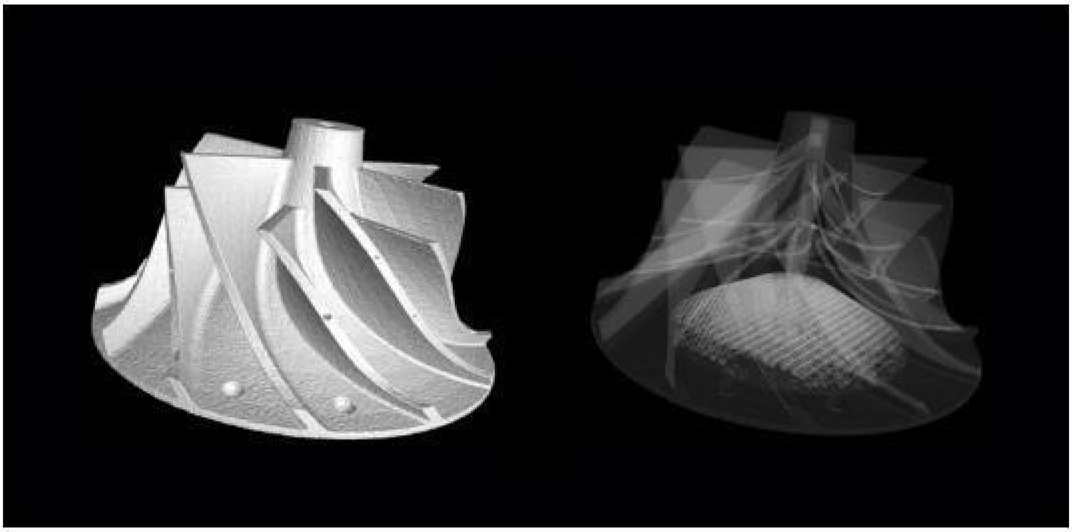

Figure 9. Scans can reveal external and internal features for checking [24]

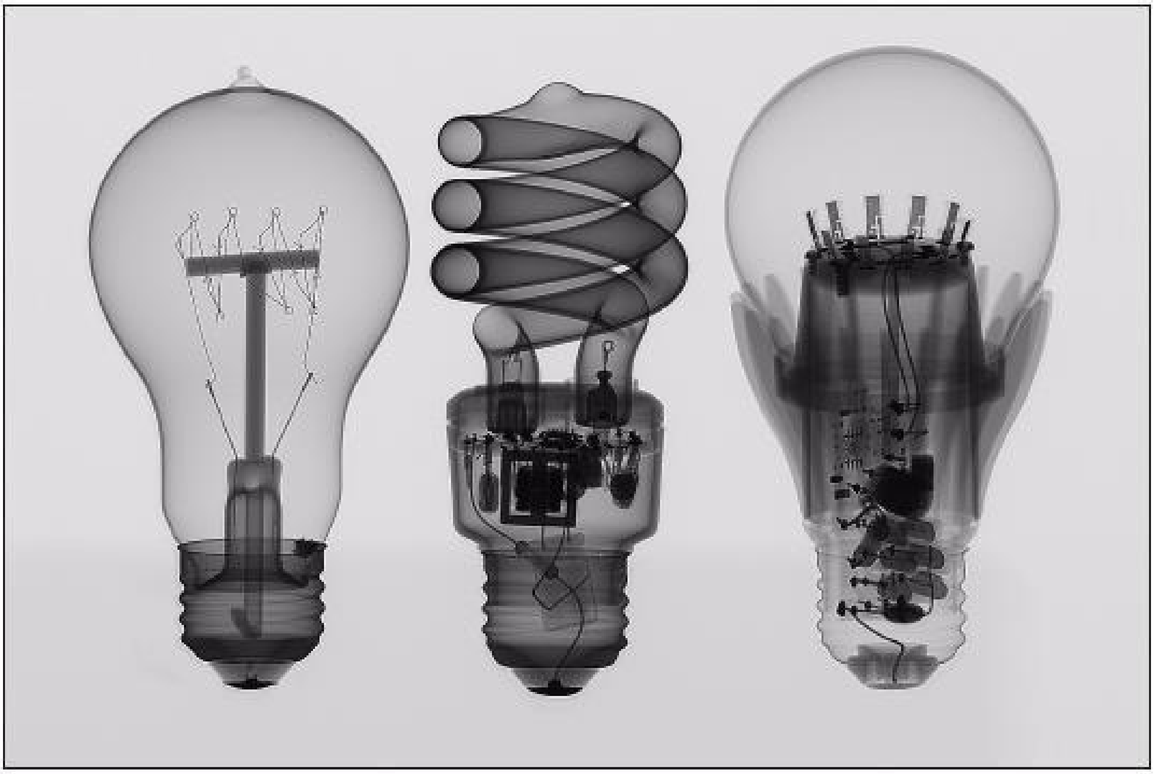

Figure 10. CT image by Herminso Villarraga-Gómez demonstrating the capabilities of micro CT technology. From left to right: an Edison-style incandescent bulb, a fluorescent light bulb and an LED bulb [24]

Tomography has also provided massive contribution in powder industry. Dawning of a new era, the use of modern production skills in the adoption of new information technology plays a key role in economic competitiveness [25]. Industry revolution 4.0 encourages the convergence of smart systems for manufacturing and advanced information technology. In this recent age, additive manufacturing (AM) is regarded as an integral ingredient. It is important to implement non-conventional manufacturing method due to the need of mass customisation and manufacturing in Industry 4.0. Thus, because of its ability to build specialized objects with sophisticated features (new materials, shapes), AM has become a leading technique for manufacturing customised goods.

Therefore, monitoring on the cross contamination of AM is required in order to utilize the manufacturing output efficiency. The laser powder bed fusion or known as L-PBF cross contamination Additive Manufacturing (AM) might change the chemical properties and shear stress in a component internally. It may also lead to fault formation and ultimately, reduce the mechanical efficiency of a part. Jamshidina et al. [26] implement an X-Ray Computed Tomography (CT) to monitor the in-process and cross contamination due to the tungsten powder particles in the consecutive layers. The 3D image reconstruction of the specimen that have been contaminated with the tungsten powder particle was illustrated in Figure 11 below where seventeen layers been detected contaminated with tungsten powder. Meanwhile, white stars labelled on the figure indicate the missing layer in the second layer from bottom. The image produced from figure below indicate that L4 and L6 have the minimum and maximum amount of powder deposited captured by the CT respectively [26].

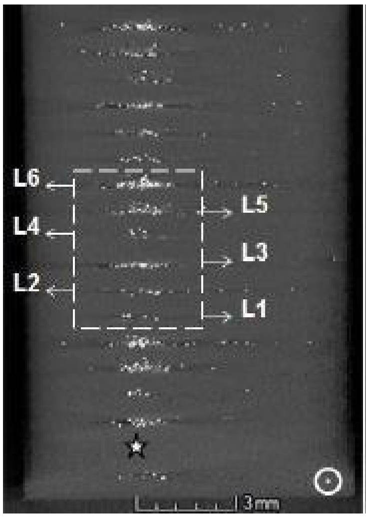

Figure 11. The vertical cross-sectional views of the specimen contaminated by the tungsten [26]

Figure 12 shows the horizontal view of the distribution of tungsten powder in the six layers of contamination. A noticeable match was observed between the calibration images shown in Figure 38 and the actual distribution within the sample [26].

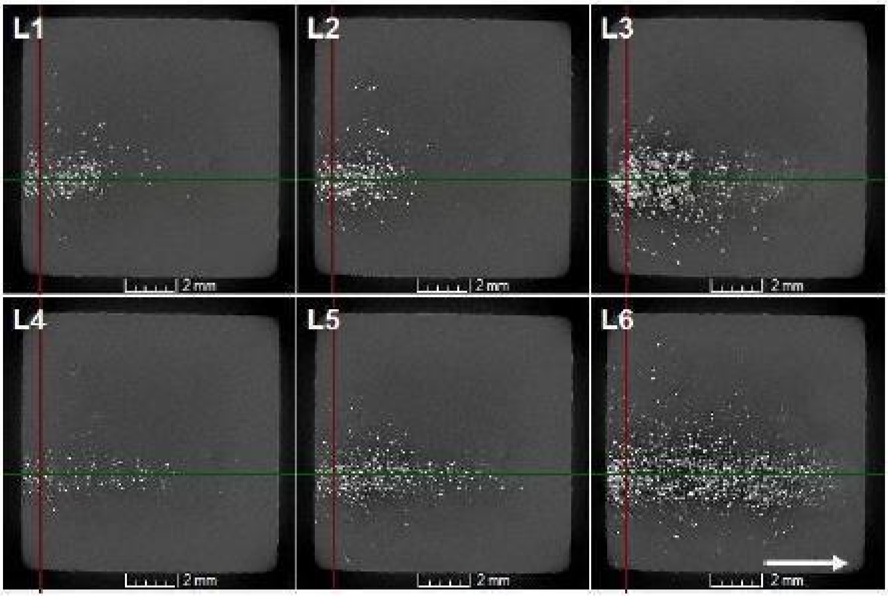

Figure 12. The horizontal cross-sectional views of the specimen contaminated with the [26]

In addition, Sinico et al. [27] study the characteristic of input material by using the cone-beam CT approach. Their work is to examines the ability and limitation of industrial microfocus CT (μ-CT) as one of the all-in-one method to describe the structure of metallic Additive Manufacturing (AM) powder, the variation of particle size and, possibly, the contamination of the feedstock powder, this work examines the ability and limits of industrial microfocus CT (μ-CT). This research strongly suggests the potential of μ-CT in detecting and eventually the degradation for cross-contamination of AM metal powder.

Apart from that Plessis et al. [28] identify a method for high resolution micro-CT scans and could provide detail analysis on the particular metal powder which is the Ti6A14V the common for laser powder bed fusion processes. This framework for image recognition gives data on internal (open or closed) porosity, particle size distribution (volume, field, sphericity) and the existence of contaminants such as higher density particles. The CT scan image below (Figure 13 and 14) shows clearly the pore space indicated in black circles and the 3D surface view of the exterior morphology of the particle.

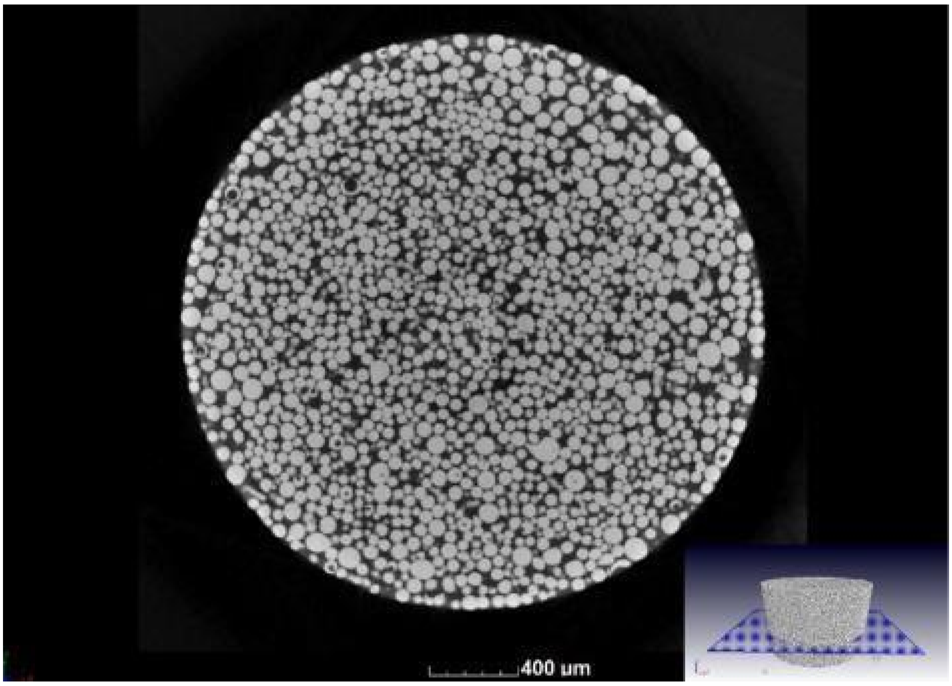

Figure 13. T slice image clearly indicating particles with pore spaces (blackcircles) [28]

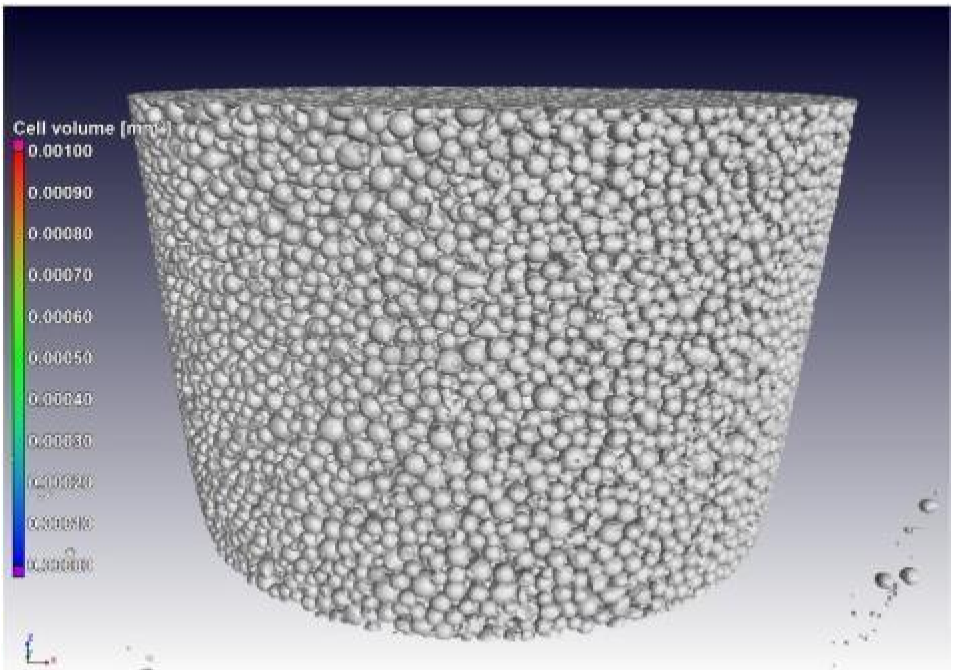

Figure 14. CT scan results showing 3D surface vie [28]

Next are the figures (Figure 15 and 16) for the 3D image of porosity analysis in terms of its size diameter and cross-sectional 2D image of particle size analysis respectively [28].

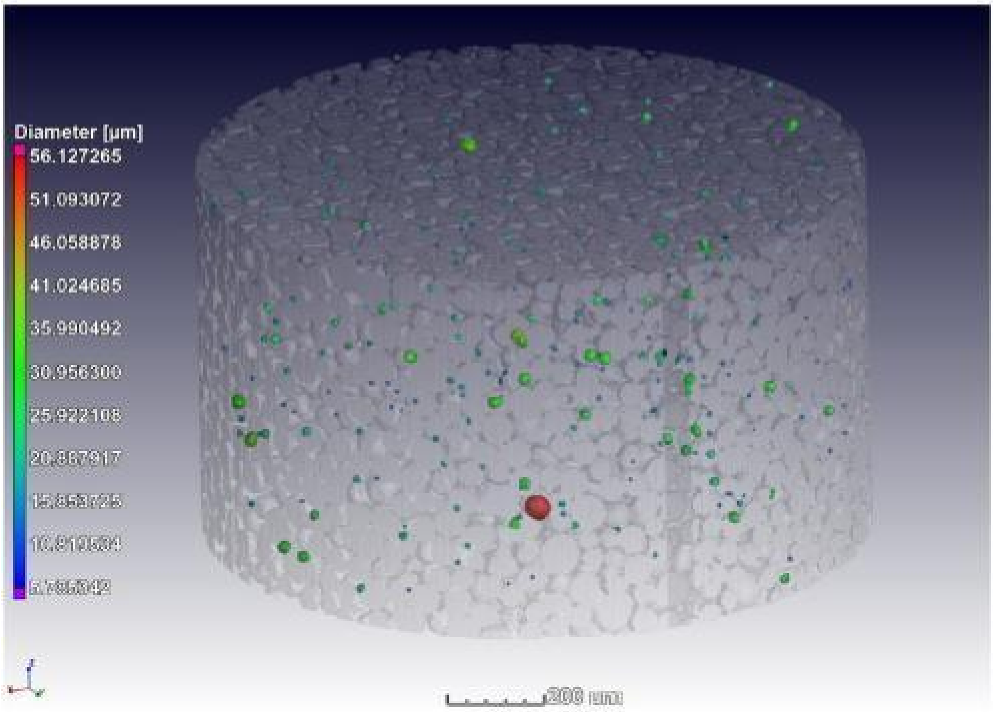

Figure 15. Porosity analysis of powders [28]

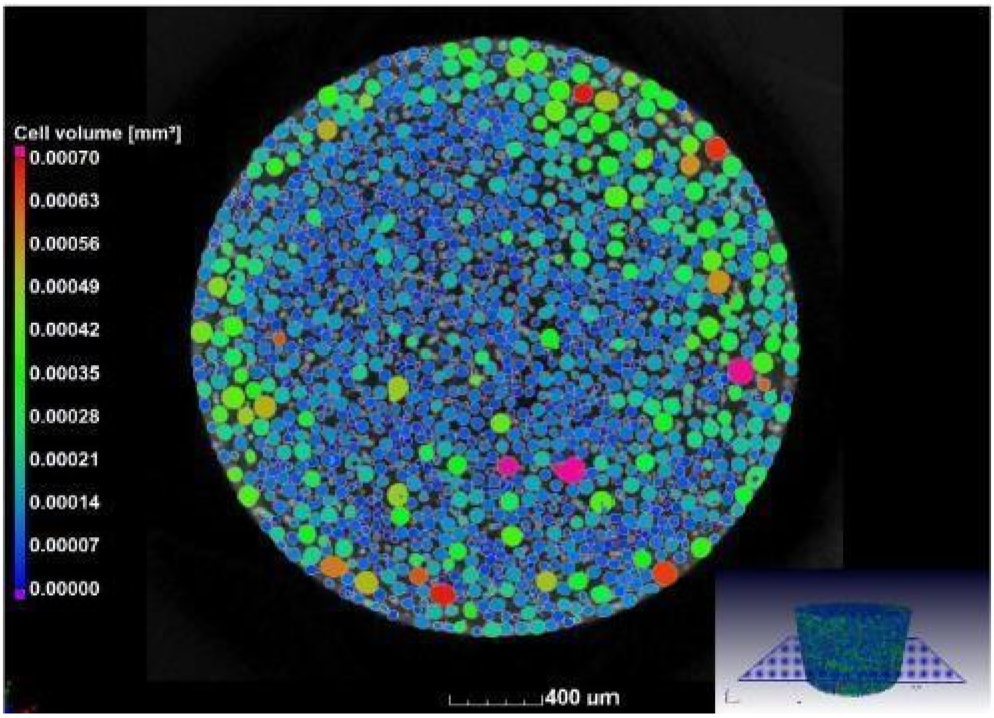

Figure 16. Particle size analysis - colour coding based on individual volume [28]

4. Conclusion

The concept and big picture of fourth industrial revolution allow efficient, smart, effective, development of individual and personalised production at the reasonable price. With the aid of smarter devices, smaller sensors, cheap data processing and transmission enhance the communication from each other. This paper has highlighted the hardware and software framework on difference type of tomography system and its significant output to the mechanism efficiency. Tomography approach provide assembly analysis and reverse engineering technology where the feedback mechanism is dynamic and accurate. Tomography system has promising a better monitoring and analysing approach through image reconstruction and eventually contribute as an essential role in industrial revolution. The collection of data from production lines and optimisation of that data result into effective machine, energy saving and scheduling of optimised maintenance Furthermore, instead of its contribution in avoid false and losses in manufacturing, discussion on CSS pipeline monitoring also proved the capability of tomography to prevent harm to human life. In conclusion, this paper proven the ability and potential of tomography framework in the various sector of fourth industrial revolution.

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