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Review and Analysis on Medical Tomography Improvement

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ABSTRACT

Medical Tomography is a technique to identify the condition underneath body tissue. It relates to identifying the health condition or certain diagnosis affirmation. Medical tomography for diagnostic imaging has been used for over a century. However, tremendous advances due to some limitations of existing medical tomography have been significantly growing in recent 30 years. MRI (Magnetic Resonance Imaging), CT-Scan extended to PET and SPECT, Ultrasound Imaging and Optical Imaging are the established modalities in medical diagnosis imaging. Radiation effect, high cost, speed, poor tissues penetration with low imaging resolution, are some issues on the established ones. This paper discusses the reviews of modern medical tomography improvement to cope with the existing diagnostic medical imaging limitation based on literatures. The review focuses on two points of views: the sensing modality or data acquisition and image reconstruction method innovation. Those two components are complimentary to each other. Less measurement will normally shift the load of producing good quality of reconstructed images to its image reconstruction algorithm. Hence comprehensive discussion on those two points of view is done. The main intention of the presented medical tomography – innovations is to improve the patient's comfort and safety, effective data acquisition process, simpler device and maintaining good quality on the reconstructed medical images. In addition, this paper also presents open research opportunities derived from the mapping analysis.

Keywords:
Medical tomography; diagnostic imaging; image reconstruction; sensor modality

1. Introduction

Medical Tomography is a technique of sensing the human's body to get the detail imaging on the underneath [1,2]. It will support medical diagnosis, which plays a vital role in medicine [2-4]. Medical Tomography is an engineering aspect that supports medical practice. Hence, its development incorporates various disciplines outside medicine. It involves engineering, basic science and computer science disciplines.

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Computed Tomography (CT) extended to PET (Positron Emission Tomography) and SPECT (Single Photon Emissions Computed Tomography), MRI (Magnetic Resonance Imaging), Ultrasound Imaging and Optical Imaging, are the common existing medical imaging modalities. Some of them, CT, PET, and SPECT, contribute to the ionizing radiation exposure to the patient. MRI, Ultrasound Imaging, and Optical tomography do not share the disadvantage of the radiation. However, MRI is a relatively high-cost modality. The sensing speed is also linear to the dimensionality, the number of spatial frequencies measured. It is a barrier in the advance of MRI implementation on the medical daily routines. The huge device of MRI make MRI machine is not available in every medical facility. Ultrasound and Optical Tomography are considered the safest medical tomography modality. However, they deliver poor tissue penetration which leads to low-quality images beyond the surface [5].

Ideal medical tomography requires safety to the patient, good imaging quality and speed on the sensing process. Those three goals might be conflicting on each of medical tomography imaging techniques. MRI is considered safe for patients and produces imaging with high detail [5]. However, the speed and the size of the hardware are its limitation. Ultrasound and Optical are considered fast but produce low quality medical imaging [5]. CT, PET, SPECT produce good quality medical imaging with quite fast sensing process. However, they have radiation issues which relate to patient's safety.

This paper discusses the review mapping of medical tomography innovations dealing with the goal of patient's safety and comfort, effective data acquisition process, simpler device and maintaining good quality of the resulted medical image. The analysis is presented in two points of views: sensing modality innovation and image reconstruction method innovation. This paper also presents the research potential in tomography imaging derived from the review analysis.

2. Medical Tomography

2.1 Tomography System

Tomography is a medical imaging technology used to create cross-sectional images of the body's inner structures [5,6]. The techniques allow medical professionals to examine the internal details of the body without having to perform surgery. Overall, tomography systems play an important role in the diagnosis, management and treatment of various diseases and medical conditions, by providing valuable information to medical professionals.

The main purpose of medical tomography is to provide detailed and accurate images of the internal structure of the human body or other objects. With the visual information produced by tomography techniques, medical professionals can more effectively diagnose, treat, and monitor diseases or health conditions. Medical tomography assists doctors and healthcare professionals in diagnosing diseases, injuries, or medical conditions by providing clear images of organs, tissues, and structures in the body. It can help identify diseases such as cancer, structural abnormalities, and other problems. By viewing cross-sectional images of the body, doctors can better plan medical or surgical procedures. They can determine the exact location for medical action, avoid sensitive tissues, and minimize risks. Tomography allows monitoring of disease progress or response to treatment. By comparing images from various times, doctors can see how the condition is changing and whether the given therapy is effective.

Tomography speed refers to how fast the imaging procedure is performed and how long it takes to take the necessary images [5,6]. The speed of tomography may vary depending on the specific technique used, the technology of the imaging equipment, the desired resolution, and the area of the body being scanned. It is important to also consider patient's comfort during scanning. The balance between speed and image quality is carefully considered by medical professionals when performing tomography procedures.

2.2 Existing Established Medical Tomography Modality

Numerous sophisticated methods have been devised and can be elucidated based on their operational principles, utilization in medical laboratories, and contributions to the evolution of imaging technologies. Among the advanced medical imaging techniques are computed tomography (CT) extend to positron emission tomography (PET) and Single-photon emission computed tomography (SPECT), magnetic resonance imaging (MRI), digital mammography, and sonography [5,6]. These techniques are fully utilized to facilitate an understanding of their benefits and application in the diagnosis, control, and treatment of various conditions such as cardiovascular ailments, cancer, neurological disorders, and traumatic injuries.

2.3 Image Reconstruction in Medical Tomography

In general, medical tomography imaging consists of two main parts. The sensing measurements process which is known as *forward problem* and the projection of the imaging inside the sensing domain which is known as *inverse problem* that is also determined by image reconstruction [1,7]. The intention of image reconstruction in medical tomography is to project the certain region of interest inside the sensing domain by utilizing a set of measurement data at the boundary of the sensing domain. Mathematically, it can be defined as finding $z \in R^l$, that satisfy [1],

$$m = Pz, \qquad m \in R^k, P \in R^{kxl} \tag{1}$$

where m is observed or measurement data, while z is the projected region of interest (medical image). P represents the mapping function that describes the physical phenomenon that relates the measurement data with the projected medical image. In numerical approach it is a measurement matrix in *kxl* dimension. In real life, the ideal data presented in Eq. (1) is perturbated by some noise that can be represented as Eq. (2) [1].

$$m = Pz + e, \qquad e \in R^k \tag{2}$$

where *e* is the measurement noise that is produced during the sensing process. Finding *z* is the inverse problem of Eq. (2).

The interesting issue in medical image reconstruction is the fact that finding *z* is not well-posed. In medical tomography imaging, the dimension of measurement data is normally much lower than the dimension of projected *z.* hence, finding the unique projected image *z* cannot be guaranteed. It is determined as ill-posed problem. Various proposed image reconstruction algorithms are intended to solve this problem.

3. Macro Issues on Medical Tomography

In general, Standard data acquisition system on the established medical tomography modality requires large bandwidth, high-rate sample and quantizer which leads to large and expensive hardware -intensive system and high energy system. In medical tomography, high-rate samples often translate into long scanning time or high radiation dosage [8].

Diagnostic imaging supported by Medical Tomography requires several criteria. Safety for the patient, good imaging quality, fast speed on sensing time (data acquisition) and simple device are some ideal objectives on medical tomography system. Innovations in medical tomography manage to overcome some issues on Medical Tomography based on the ideal criteria.

3.1 Radiation Potential

Some of current established medical diagnostic tomography or imaging contribute to the radiation issue. X-Ray, CT-Scan, PET, SPECT utilize ionizing exposure to extract the patient's body tissue detail imaging [5,8]. The radiation issue is becoming crucial on pediatric CT [9]. Moreover, the standard data acquisition system requires high-rate sampling which leads to high radiation dosage. These ionizing based medical tomography has been widely used until today due to its cost effectiveness and affordable imaging quality. However, some innovation to reduce the radiation effect has been delivered.

3.2 Data Acquisition

MRI currently is the most powerful medical diagnostic tomography system. It provides high resolution with high detail medical image. Its magnetization sensing is also free from radiation impact hence safe for the patient [10,11]. However, the data acquisition process takes quite a long time with high-rate sampling. The sensing patient should stay still in the MRI sensing device for 20 to 40 minutes. It can affect claustrophobia for some patients [11]. The high-rate sampling will also linearly affect the cost, which is considered high.

3.3 Device Design

Established powerful medical imaging tomography such as MRI and CT are very iconic with very large devices which require high energy resource. Due to this large device, its availability cannot be easily provided for any kind of healthcare facilities. Those tomography modalities are only available in large hospitals which are normally located in big cities.

3.4 Imaging Quality

Innovation on handling radiation effect and high-rate sampling produces electrical based tomography modality and under-sampling measurements frameworks. Many works have been demonstrated. However, the resulting imaging quality is still a big issue. Electrical based tomography modality is a soft-field type of tomography which is very sensitive to the sensitivity map or sensing design [1]. It affects the artifacts and elongation error on the producing medical image. Hence, constructing the sensing design device and its image reconstruction method are still very challenging.

Under-sampling measurements framework on the established medical tomography system produces lower resolution with less detail of the medical image [11]. It might help to reduce the radiation effect, cut the cost, and make the faster acquisition time. However, preventing affordable medical imaging quality should be optimized for this framework.

4. Medical Imaging System Improvement Innovation Mapping

Dealing with the macro issues on medical tomography as presented in chapter III, various innovations have been delivered by many researchers to limit the disadvantages by improving less to non-invasive and faster medical imaging. This paper presents the mapping of the innovation into two points of views: the sensing framework (modality and data acquisition method), and the image reconstruction method.

4.*1 Sensing Framework (Sensing Modality and Data Acquisition)*

Intend to limit the radiation effects and cope to the data acquisition issues, various sensing frameworks in terms of modality and data acquisition method have been investigated and developed. In general, the approaches can be described as below Figure 1 below.

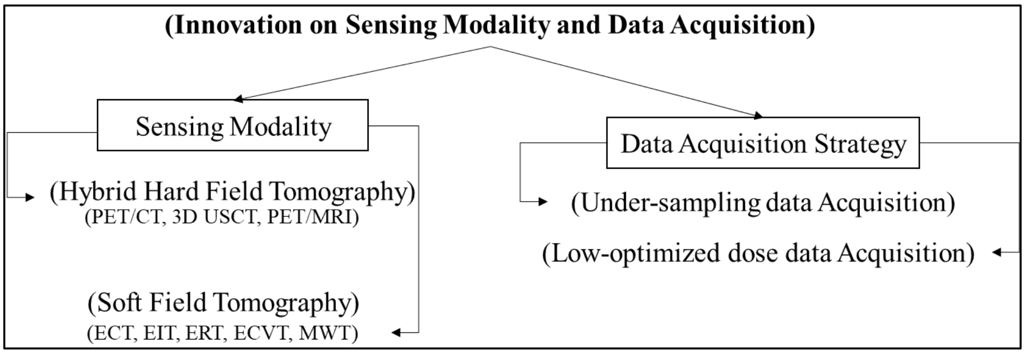

Fig. 1 Sensing and data acquisition innovation for medical tomography improvement

In terms of sensing framework, based on the observed scientific reports, there are two innovative approaches which promote the soft field tomography and hybrid hard field tomography modalities. The development of soft-field tomography is strongly related to radiation reduction issues [7]. This tomography modality is non-invasive with no radiation effect. It has been widely explored for medical imaging [3,12-15]. Mostly soft field tomography modality is electrical based tomography. ECT (Electrical Capacitance Tomography) [16], EIT (Electrical Impedance Tomography) [12], ECVT (Electrical Capacitance Volume Tomography) [14] and MWT (Microwave Tomography) [17] have been explored to do medical sensing. The advantages of this tomography modality are its low energy and simple device that supports portability [1].

The most challenging issues in soft field tomography are the high under determined system in the image reconstruction phase [1,4]. Sensor design limitation which leads to less dimension of measurement values compared to the dimensions of projected imaging inside the sensing domain, make the so called ill-posed inverse problem on the image reconstruction phase. It produces elongation error on the resulted image reconstruction [1]. In sensor design point of view, some researchers have been working on how to produce more measurements data with challenging arrangement on the electrode [18]. In reconstruction point view, mitigating the good quality of imaging with less measurement data is challenging issues. It is discussed in the next sub chapter.

Limiting the radiation effect and some problems on data acquisition is also mitigating by promoting some data acquisition strategies. The under-sampling data acquisition and low optimized dose data acquisition are currently highly investigated [2,5,11,19]. The terminology under-sampling data acquisition is mostly for non-radiation tomography modality while the low optimized dose data acquisition is for radiation-based tomography modality. Under sampling data acquisition object to reduce the scanning time by sampling the measurement data. It can reduce the cost and some uncomfortable effect on the sensing process such as on MRI. Under-sampling MRI has been recently highlighted.

Low optimized dose data acquisition reduces the dose of the transmitted ionizing radiation during the sensing process. Some advanced medical imaging such PET/CT Hybrid, three-dimensional ultrasound computed tomography (3D USCT), and simultaneous PET/MRI have been developed to reduce the ionization dosage while preventing the high imaging resolution [8,5]. Both approaches will surely affect the quality of the result of the projected imaging. Hence, research on developing image reconstruction algorithms for these data acquisitions techniques has been interesting.

4.2 Image Reconstruction Method

The main objective of having medical tomography is its imaging of the sensing domain to be used as medical diagnostic analysis. Hence, besides the sensing technology, the robust image reconstruction method is highly required to produce readable images. In addition, as presented before, some innovations on sensing phase point of view to cope with radiation and data acquisition issues lead to the requirement of development of appropriate image reconstruction algorithm too. This sub-chapter presents the mapping of developing image reconstruction techniques for hard-field medical tomography modality and soft-field medical tomography modality.

5. Hard-Field Tomography Image Reconstruction

As presented before, current established medical tomography is mostly a hard field. Along with its advantages and limitations, all the developed image reconstruction algorithms object to improve the imaging quality with limiting the negative effect possibility. Figure 2 below presents the mapping of image reconstruction technique on various hard field medical tomography system.

Based on published research, there are at least five (5) clusters of image reconstruction approach for hard field tomography. Physical model-based reconstruction is an image reconstruction approach which is developed based on the mathematical modelling of the physical sensing process [6,20]. It is more an analytical approach which is commonly developed in the early stage of tomography imaging development. Inverse Fourier filtered back projection and Algebraic Reconstruction Technique are some methods based on this approach [6,20].

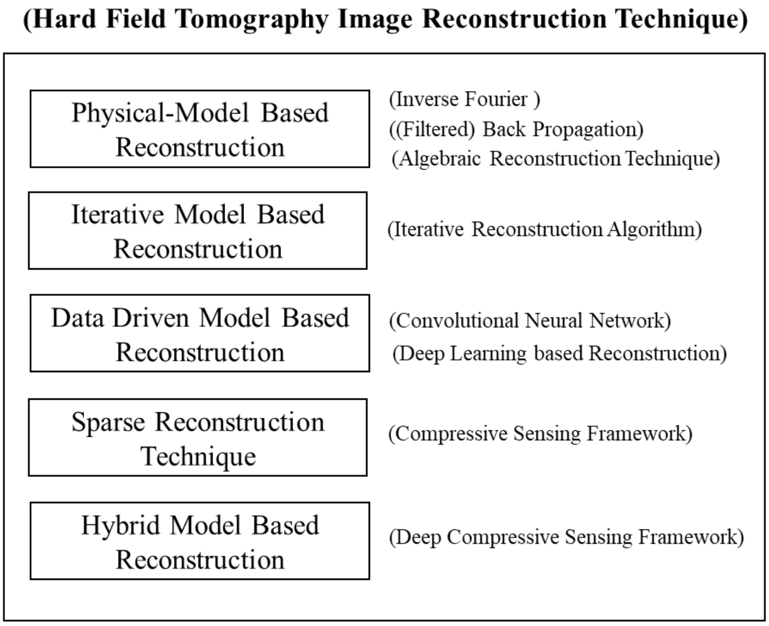

Fig. 2. Image reconstruction technique on field medical imaging tomography system

The optimization version of this approach is followed by various iterative reconstruction algorithm techniques. It iterates the early imaging approximation subject to certain penalty error. L-norm optimization is commonly used as the objective function [21,22]. In the era of data, data-driven models based on reconstructing images are massively developed [2,23-25]. Artificial Neural Network up to its advancement on Deep Learning frameworks are utilized to capture the mapping model between measurements data and projected image information. It is considered black box modelling.

In hard-field tomography, deliberate reduction to reduce radiation potential or faster data acquisition objective is applied. Hence, its reconstruction does not meet the Shanon-Nyquist requirements. Shanon-Nyquist requires at least providing 2 times frequency of sampling to guarantee qualified reconstruction [7]. Practically, it requires more than 2 times of frequency of sampling which related to the bandwidth issue too. Subject to this issue, Compressive Sensing framework for solving under-determined inverse problem on this kind of problem has been developed. This framework enables reconstructing the signal (image) with less sampling measurement as Shanon -Nyquist requirement if the sparsity of the reconstructed signal (image) can be guaranteed. Some works on adopting and developing tomography image reconstruction have been done by [8,10], which mostly cover the under-sampling or low dose tomography imaging. The challenges on adopting compressive sensing for medical image tomography is to guarantee the sparsity and its sparsity meets the comprehensive sensing requirements. Hence, designing appropriate sensing matrix and dictionary on this field are high research’s focus.

Recent works on some hybrid models which combine data driven approach and compressive sensing framework have been done [8]. It applies deep learning to search optimal sensing matrix design on compressive sensing framework to produce more accurate image reconstruction.

6. Soft-field Tomography Image Reconstruction

Dealing with the effort of energy consumption reduction and radiation elimination, exploring medical tomography using soft-field modality have been explored. Some physical limitations on the sensor domain make the high challenge on the image reconstruction part. Compared to hard-field tomography system, image reconstruction on soft-field is considered a highly under-determined system which harder to solve [1,26]. Based on the published research paper, image reconstruction on soft-field tomography can be divided into two approaches: direct method and in-direct method [26]. The difference of these two approaches on the measurement requirement to reconstruct the image in the sensing domain [26]. Direct approach can directly reconstruct any intended ROI (region of interest) by utilizing the corresponding measurement values. While in in-direct approach, it requires measurement on all sensing domain to get the image reconstruction. Mapping of the image reconstruction methods on medical soft-field tomography system is presented in Figure 3 below.

Direct image reconstruction approach is more on analytical approach while the in-direct image reconstruction utilizes some techniques on approximation optimization. Calderon [27], Dbar [28], Enclosure [29] and Generalized Polarized Tensor (GPT) [30] are some methods that have been developed as direct approaches on reconstruct image on electrical based tomography system. GPT is reported to be the most powerful one on this approach [30]. Not many researchers contributed to this direct image reconstruction field, due to the high mathematical model complexity. In in-direct image reconstruction approaches, the existing image reconstruction method can be divided into four (4) clusters: iterative based model reconstruction, Sparse reconstruction, data driven model and hybrid model [26].

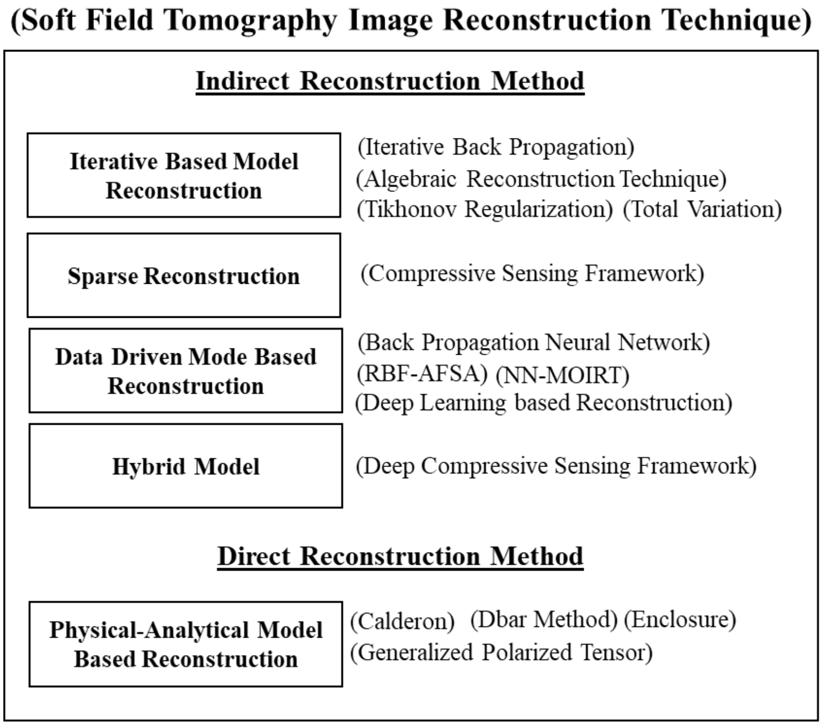

Fig. 3 Image reconstruction technique on hard-field medical imaging tomography system

Sparsity reconstruction approaches on soft-field tomography is applied due to its natural high under determined system on the image reconstruction. The dimension of measurement values produced by soft-field tomography is much lower compared to hard-field tomography. While the dimension of the projected image is similar. Hence, the inverse problem becomes more difficult. The compressive sensing approach has been explored to deal with the medical image reconstruction with less measurement values dimension [1,4]. It has been shown that this approach is quite powerful to present quality imaging with less elongation error [1,7]. Constructing sensing matrix design, dictionary and sparse reconstruction method are some research opportunities on Compressive Sensing for medical imaging [1,7,31-33].

7. Potential Research and Development

As presented above, the innovation on providing less up to non-invasive medical image tomography can be seen from two points of view. Both provide open wide research development opportunities. Electrical based tomography has been widely explored for medical imaging proposes due to its advantage as the non-radiative and low energy tomography modality. It is safe for multiply usages. However, the challenge of electrodes arrangement to acquire optimum measurement data while inhibiting measurement error at the same time are still very challenging research development. In reconstruction point of view, the soft field property on the electrical based tomography produces elongation error on the reconstructed image. Hence, improved mathematical modeling on the reconstruction method is highly required to eliminate or minimize the elongation error. Some works have been presented [7] which still need further improvement.

The issues around established medical imaging is on reducing the radiation effect to make it safer for the patient. Various works on low optimized-dose and under-sampling data acquisition have been done [11,19]. This approach has consequences on the reduction of measurement data which is strongly related to the quality of the projected image reconstruction. The research is still very open on how to appropriately sample the data to make sure the gathered one is the most significant one. This is very typical subject to the physical characteristics of the tomography sensor modality and its sensing methodology. Low optimized-dose and under-sampling data acquisition lead to high under determined system which hard to solve. Fundamental research on proposing image reconstruction due to this condition is still open subject to required improvements on previous works [5].

8. Conclusions

This paper discusses the review mapping of medical tomography innovations dealing with the goal of patient’s safety, effective data acquisition process, simpler device and maintaining good quality of the projected medical image. Improvement on medical tomography system have been developed from the sensing and data acquisition point of view and the image reconstruction method point of view.

In terms of the sensing and data acquisition point view, medical tomography improvement focuses on increasing the safety and conformity of the patient during the sensing process. Some innovations on developing soft-field tomography modalities have been explored to provide non-radiation, low energy, and portable medical sensing. It is not only intended to increase the safety and conformity of the patient but also improve the availability easiness for every healthcare facility. The challenge on this medical tomography modality is on the soft field property which lead to elongation error to the projected imaging and sensor design that led to complex measurement data arrangement. Various improvements on the existing established medical tomography system (CT, USG, MRI, etc) have been done with the same objective. Under-sampling and low optimized dose measurements are explored to reduce the scanning time, bandwidth, and radiation effect. The challenge of this approach is to provide appropriate sampling masking subject to its physical sensor characteristics. In addition, the less captured measurement data leads to the challenging issues on maintaining high quality of the projected image reconstructions.

In sequence of some improvement on medical tomography sensing and data acquisition methodology, it implies various challenges on the image reconstruction techniques. All the proposed improvements in the sensing and data acquisition lead to the under-determined system on the image reconstruction which is hard to solve. Various methodologies have been proposed. Research on maintaining the quality projected image reconstruction with less measurement data is still widely opened.

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