Bin Zheng
Stefan Andrei
Md Kamruzzaman Sarker
Kishor Datta Gupta *Editors*

Data Driven Approaches on Medical Imaging

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Bin Zheng • Stefan Andrei •
Md Kamruzzaman Sarker • Kishor Datta Gupta
Editors

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Editors
Bin Zheng
Norman, OK, USA

Md Kamruzzaman Sarker
Department of Computer Science
Bowie State University
Bowie, MD, USA

Stefan Andrei
Department of Computer Systems
Engineering and Technology
Oregon Institute of Technology
Klamath Falls, OR, USA

Kishor Datta Gupta
Department of Cyber Physical System
Clark Atlanta University
Atlanta, GA, USA

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Preface

In this book, named *Data-Driven Approaches to Medical Imaging*, the authors delve into the complex world of medical imaging, examining how procedures have changed over time, how cutting-edge technology have been incorporated, and the ethical considerations that support this important discipline. Modern medical imaging has advanced significantly, transforming healthcare by enhancing patient care, diagnosis, and treatment planning. While retaining diagnostic quality, advances in CT and other X-ray-based imaging technologies have resulted in considerable radiation dose reductions. To help radiologists and physicians understand pictures, AI and machine learning are being integrated into medical imaging. Faster and more precise diagnoses may be made by using AI to find patterns, abnormalities, and probable illnesses. Pharmaceutical research and medication development are critically dependent on contemporary medical imaging. It enables the cellular and molecular-level evaluation of medication effects. In the upcoming years, the area of medical imaging is expected to be considerably improved by the increasing integration of technology, artificial intelligence, and data analysis.

The book covers a wide range of subjects, including ethical issues in decision-making and medical imaging technologies. This research book consists of 10 chapters which are based on significant medical topics. The journey starts with a thorough analysis of the many medical imaging modalities, such as X-ray, CT, and MRI. These technologies have improved in terms of accuracy, speed, and intrusiveness. This first chapter is about "Introduction of Medical Imaging Modalities." The writers explain the fundamentals and developments of each modality, illuminating its technical complexities and diagnostic possibilities. They give a thorough breakdown of the diagnostic resources available to medical professionals while highlighting the advantages and disadvantages of each procedure. In the second chapter called "Introduction to Medical Imaging Informatics," the book examines the fusion of information technology and medical imaging in the field of medical imaging informatics. It focuses on the role of informatics in improving diagnosis, treatment planning, and patient care as it explores the integration of data management, analysis, and sharing. The following chapter is "Active Learning on Medical Image." In the constantly changing field of medical imaging, Active

Learning on Medical Images stand out as essential elements. The bulk of medical imaging datasets include scant information, which might make it difficult for machine learning algorithms to understand patterns. Another major problem for machine learning is the dearth of labeled data. Active learning strategies can be used in this situation to overcome the problem of having little annotated medical picture data. In active learning, the most informative samples are iteratively chosen from a huge pool of unlabeled data for expert interpretation. The fourth chapter is about "Few Shot Learning for Medical Imaging: Few-shot learning approaches have drawn a lot of attention in the field of medical imaging, where data might be sparse and labeling samples can be costly or time-consuming to acquire. A Comparative Analysis of Methodologies and Formal Mathematical Framework." The techniques described in the book enable machines to learn and adapt from small datasets, providing more precise and effective diagnosis. Another important area of focus is the incorporation of Automated Machine Learning (AutoML) Systems in medical imaging which is described in the chapter "AUTOML Systems for Medical Imaging". The authors show how these systems streamline the diagnostic procedure and improve accuracy by optimizing model selection, feature engineering, and hyperparameter tweaking. The sixth chapter is about "Online learning for X-Ray, CT or MRI." The field of X-ray, CT, and MRI imaging has a dynamic component thanks to the use of online learning. The book demonstrates how real-time online learning can adjust to fresh information and alterations in patient circumstances, improving diagnostic accuracy and patient outcomes. In the seventh chapter, named "Invariant Scattering Transform for Medical Imaging," the authors described that the ability to generate invariant representations of pictures makes IST particularly useful since it makes medical images resistant to numerous deformations and modifications. The potential of Invariant Scattering Transform for medical imaging is investigated, offering a unique viewpoint on feature extraction. The authors go into detail on how this method can increase the reliability and understandability of medical picture analysis. The topic of Generative Adversarial Networks (GANs) for Data Augmentation is explored in depth in this book which is discussed in the chapter called "Generative Adversarial Networks for Data Augmentation." It demonstrates how GANs may create accurate medical images artificially, increasing small datasets and enhancing the training procedure. The next chapter is "Bias, Ethical Concerns, and Explainable Decision-Making in Medical Imaging Research." The authors discuss bias, ethical considerations, and explainable decision-making while discussing the ethical aspects of medical imaging. Especially in delicate medical circumstances, they stress the significance of justice, accountability, and openness in algorithmic decision-making. The final chapter is named "Case Studies on X-Ray Imaging, MRI and Nuclear Imaging." Case Studies on X-ray imaging, MRI imaging, and nuclear imaging serve as the exploration's climax. These real-world examples explain how the concepts are used in practice, linking the theoretical and practical worlds. These case studies show how X-ray, MRI, and nuclear imaging are vital diagnostic and therapeutic techniques for treating a range of medical diseases. They also include important information about patient care and treatment options. This book provides readers with a diverse view of a sector that is still revolutionizing healthcare, from cutting-edge procedures to moral quandaries.

We would like to extend our heartfelt gratitude to all those who have played an instrumental role in making this book a reality. Without the collaborative effort and collective wisdom of numerous individuals, this publication would not have come to fruition.

First and foremost, we extend our deepest appreciation to the editorial team who worked tirelessly to ensure the quality and integrity of this work. Your meticulous attention to detail and unwavering commitment to excellence have been invaluable. We are particularly grateful for your expertise in not just editing the content but also enriching it in countless ways.

We also wish to express our sincere thanks to Springer Publishing. The professionalism and support provided by the Springer team were second to none. From the early planning stages through to the final publication, you have been an indispensable partner. Your willingness to take on this project and see it through to its successful completion has been pivotal, and for that, we are extremely grateful.

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Norman, OK, USA — Bin Zheng
Klamath Falls, OR, USA — Stefan Andrei
Bowie, MD, USA — Md Kamruzzaman Sarker
Atlanta, GA, USA — Kishor Datta Gupta

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Introduction of Medical Imaging Modalities

S. K. M. Shadekul Islam, Nasim Md Abdullah Al, Ismail Hossain, Md Azim Ullah, Kishor Datta Gupta, and Md Monjur Hossain Bhuiyan

1 Introduction

Medical imaging is a very essential tool in the diagnosis and treatment of various diseases. It refers to the non-invasive techniques and approaches used to create visual representations of the internal organs and tissues of the human body. These visual representations, also known as images, can be used to detect and diagnose a variety of diseases, guide disease treatment strategies and monitor treatment efficacy. Specifically, medical imaging is widely used to examine and visualize different parts of the body, including bones, muscles, organs, blood vessels, and other internal structures. Medical imaging can also be divided into two main categories: diagnostic imaging and therapeutic imaging [1]. Diagnostic imaging, which is used to detect and diagnose diseases, and determine disease severity, include modalities such as X-ray radiography, computed tomography (CT), magnetic resonance imaging (MRI),

S. K. M. Shadekul Islam · N. Md Abdullah Al (✉)
Research and Development Department, Pioneer Alpha, Dhaka, Bangladesh
e-mail: shadekul15-12836@diu.edu.bd; nasim.abdullah@ieee.org

I. Hossain
School of Computing, Southern Illinois University, Carbondale, IL, USA
e-mail: ismail.hossain@siu.edu

Md. A. Ullah
University of Memphis, Memphis, TN, USA
e-mail: mullah@memphis.edu

K. D. Gupta
Clark Atlanta University, Atlanta, GA, USA
e-mail: kgupta@cau.edu

Md. M. H. Bhuiyan
School of Aerospace and Mechanical Engineering, University of Oklahoma, Norman, OK, USA
e-mail: mhbhuiyan@ou.edu

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ultrasound (US), and nuclear medicine. Therapeutic imaging, which is used to guide procedures such as surgery or radiation therapy, includes modalities such as fluoroscopy, angiography, and interventional radiology. With the advancements in technology, a wide range of medical imaging modalities have been developed to provide detailed visual information about the internal structures and functions of the body.

In current clinical practice, the routinely used imaging modalities include X-ray, CT, MRI, ultrasound, and nuclear medicine. Each imaging modality has its unique advantages for different applications and diagnostic purposes, and limitations to reveal the internal structure of the different organs of the body and their functions. This chapter aims to provide an overview of the most commonly used medical imaging modalities, including X-ray, CT, MRI, ultrasound, and nuclear medicine. We will discuss the basic principles, typical clinical applications, advantages, and limitations of each modality. Additionally, we will explore the latest developments and future directions in the field of medical imaging. The goal of this chapter is to provide a comprehensive understanding of the various medical imaging modalities available today and their impact on the field of medicine.

2 Background Study

Medical imaging modalities refer to the various techniques and technologies used to create visual representations of the human body for disease diagnosis and treatment purposes. In recent years we have seen a good deal of research to further improve the efficacy and image quality of many existing medical imaging modalities including X-ray, CT, MRI, ultrasound, nuclear medicine, cardiovascular imaging, electrical impedance tomography (EIT), and positron emission tomography (PET).

Additionally, Chapman's [2] X-ray imaging, also known as radiography, is one of the oldest and most widely used imaging modalities. It is based on the principle that different types of tissue absorb different amounts of X-ray radiation, allowing for the creation of detailed images of the body's internal structures [2]. However, X-ray imaging has some limitations, such as exposure to ionizing radiation and the lack of tissue contrast.

Ole Petter Wennberg et al. [3] CT scans, also known as computed tomography, use X-ray radiation to create detailed cross-sectional images of the body. CT scans are highly effective in detecting bone and soft tissue abnormalities, and they can also be used to guide biopsies and other procedures. However, CT scans also involve exposure to ionizing radiation and may not be suitable for certain patient populations.

Paul Glover [4] MRI uses a magnetic field and radio waves to create detailed images of the body's internal structures. MRI is particularly effective at imaging soft tissue and is often used to detect tumors, injuries, and other abnormalities in the brain, spine, and other parts of the body. MRI is non-invasive and does not involve ionizing radiation, making it a safer option for certain patients.

Yobo Xie [5] Ultrasound imaging uses high-frequency sound waves to create images of the body's internal structures. It is particularly effective at imaging soft tissue and is often used to image the fetus during pregnancy, as well as to evaluate organs such as the liver, gallbladder, and kidneys. Ultrasound is non-invasive, does not involve ionizing radiation, and has no known harmful effects.

Sandip Basu et al. [6] PET imaging uses small amounts of radioactive material to create detailed images of the body's metabolic processes. It is often used in conjunction with other imaging modalities, such as CT and MRI, to create more detailed images of certain diseases and conditions. However, PET imaging involves exposure to ionizing radiation and may not be suitable for certain patient populations.

In conclusion, various medical imaging modalities are available, each with its own advantages and disadvantages. X-ray, CT, MRI, ultrasound, and PET are some of the most commonly used modalities. X-ray and CT use ionizing radiation to create images, which can be harmful to the patient, while MRI and ultrasound use non-ionizing radiation, which is safer. PET uses ionizing radiation, but it is used in conjunction with other imaging modalities to create more detailed images of certain diseases and conditions.

3 Methodology

First of all in the research methodology for this chapter on "Introduction of Medical Imaging Modalities" I identified the different medical imaging modalities that will be covered in the paper such as X-ray, CT Scan, MRI, Ultrasound imaging, Nuclear medicine imaging, Electrical Impedance Tomography, Cardiovascular Imaging. The paper is focused on introducing these modalities in terms of their basic working principle, applications, limitations, and advantages.

In the second step, we conducted a comprehensive literature search using relevant databases such as Google, Google Scholar, PubMed, Scopus, and Web of Science using keywords such as "Medical Imaging Modalities", "X-ray", "CT Scan", "MRI", "Ultrasound imaging", "Nuclear medicine imaging", "Electrical Impedance Tomography", "Cardiovascular Imaging" used to find relevant studies. Inclusion/exclusion criteria such as the date range of the studies and the language of the studies are applied to narrow down the search.

Then thirdly, we carefully review and assess the quality of the studies found in the literature search, and select the most relevant and high-quality studies for the review. The selected studies covered the basic working principle, applications, limitations, and advantages of the different medical imaging modalities. Relevant information is extracted from these studies. The results are presented in a clear and concise manner, including a discussion of the strengths and limitations of the studies.

In the fourth step, we provided a conclusion that summarizes the main findings of the review. This section provides a clear summary of the key takeaways from the review.

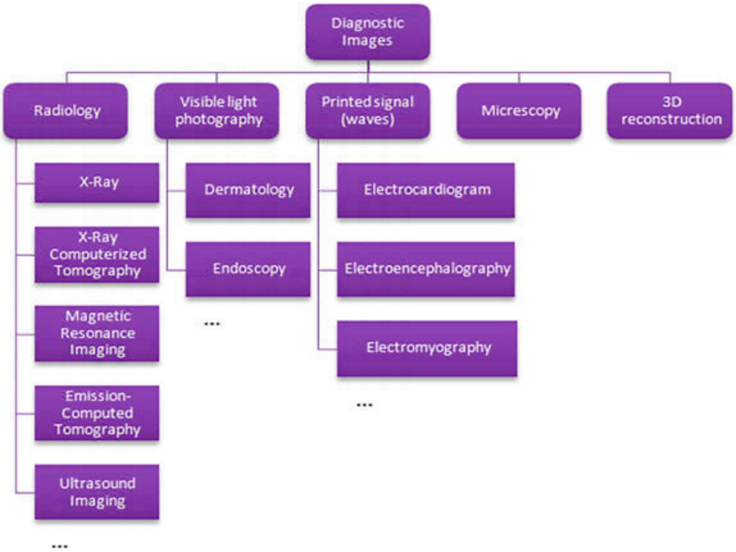

Fig. 1 The categorization of medical imaging modalities [7]

And finally, we included a reference list of all the studies that were included in the review, following the Springer citation style. This is an important step that allows other researchers to easily find and access the studies that were used in the review.

Overall, the methodology for this review paper on "Introduction of Medical Imaging Modalities" is a systematic and thorough process that will help to ensure that the review is comprehensive, accurate, and up-to-date.

Figure 1 depicts the five groups into which the diagnostic pictures are divided. As a result of the various medical technology each of these groups employs, the output images they create vary. Although all of the images fall under the same general category structure, each one has unique qualities that aid in the production of various kinds of information. The information generated by various picture modalities to deal with registration and/or fusion procedures is described in this section. In accordance with the kind of output photos, this part is divided into five subsections. These divisions are X-ray imaging, visible light photography, printed signals (waves), microscopy, and three-dimensional representation.

4 Definition of Medical Imaging

Medical imaging refers to the techniques and technologies used to create visual representations of the inside of the body [8]. These visual representations, also known as images, can be used to diagnose, monitor, or treat various medical conditions. Medical imaging can be used to examine and visualize different parts of the body, including bones, muscles, organs, blood vessels, and other internal structures.

Medical imaging can be divided into two main categories: diagnostic imaging and therapeutic imaging [1]. Diagnostic imaging, which is used to diagnose and determine the severity of a condition, includes modalities such as X-ray, CT, MRI, ultrasound, and nuclear medicine. Therapeutic imaging, which is used to guide procedures such as surgery or radiation therapy, includes modalities such as fluoroscopy, angiography, and interventional radiology.

Some common modalities include X-ray, CT, MRI, ultrasound, and nuclear medicine, each has its own indications and limitations, these modalities are powerful diagnostic tools that can reveal the internal structure of the body and its functions [9].

5 Overview of Different Modalities

5.1 X-ray Imaging

X-rays are a form of electromagnetic radiation that can pass through many solid objects, including the human body. X-ray imaging uses X-rays to create detailed images of internal structures, such as bones [10].

5.2 Computed Tomography (CT) Imaging

CT scans use X-rays to create detailed cross-sectional images of the body. These images can be used to diagnose and monitor a wide range of conditions, including cancer, heart disease, and injuries to the bones and internal organs [11].

5.3 Magnetic Resonance Imaging (MRI)

With the use of a strong magnetic field, radio waves, and a computer, MRI scans can produce very detailed images of internal structures, such as the brain and spinal cord, muscles, tendons, ligaments, and blood vessels [4].

5.4 Ultrasound Imaging

Ultrasound employs acoustic waves of very high frequency to create images of internal structures, such as the uterus and ovaries during pregnancy. It is also used to examine the organs and blood vessels in the abdomen and to guide needle biopsies [8].

5.5 Nuclear Medicine Imaging

Nuclear medicine uses small amounts of radioactive material to create images of internal structures and to identify abnormalities, such as tumors or infections. This modality is also used to diagnose and monitor certain diseases such as cancer, heart diseases, and thyroid diseases [12].

5.6 Electrical Impedance Tomography (EIT)

EIT imaging uses electrical signals to image internal structures and monitors changes in their electrical properties, such as the lungs and heart [13].

5.7 Cardiovascular Imaging

It is a subspecialty of Medical imaging that uses various modalities to visualize the structure and function of the heart and blood vessels. It includes techniques such as Echocardiography, Cardiac Computed Tomography (CCT), and Magnetic Resonance Imaging (CMR). These techniques help in the diagnosis of heart diseases, such as Coronary artery disease, valvular heart disease, and congenital heart disease. They also play an important role in guiding interventional procedures such as angioplasty and stent placement.

6 X-ray Imaging

6.1 Basic Principles

X-ray imaging, often known as radiography, is an imaging technique used in medicine for diagnosis that creates high-resolution images of internal anatomical structures like bones. The basic principles of X-ray imaging are as follows:

X-rays are a form of electromagnetic radiation that can pass through many solid objects, including the human body. This type of imaging works by directing a beam of X-rays at the area of the body being examined [2]. The X-rays pass through the body and are then detected by a special detector, such as an X-ray film or digital detector. Because bones are denser than other tissues, they absorb more X-rays and appear white on the final image, while softer tissues such as muscles and organs absorb fewer X-rays and appear darker. In order to produce a clear image, the machine must use the appropriate amount of radiation and the body part must be positioned correctly in relation to the X-ray beam. The image produced is a two-dimensional representation of the three-dimensional structure of the body, so to obtain a more complete picture, different views are taken to examine the same area from different angles. The images are then interpreted by a radiologist, who is a medical doctor who specializes in interpreting medical images, to identify any abnormalities or issues, such as broken bones, tumors, or other conditions, and provide a diagnosis.

Electromagnetic radiation, or X-rays, are created in an evacuated glass tube (the bottle in Fig. 2) [14]. High-speed electrons that have been propelled across the tube's vacuum by a significant voltage difference between the cathode and the anode are aimed at a rotating tungsten anode. X-rays and heat are released when the electrons hit the anode. The X-ray tube is inactive until the Medical Radiation Technologist (MRT) turns it on because X-rays can only be created when a voltage differential is introduced across the cathode and anode. All imaging modalities that utilise X-rays (X-ray, CT, Fluoroscopy, Angiography) use this physical, on/off configuration.

6.2 Typical Clinical Applications

X-ray imaging, also known as radiography, has a wide range of clinical applications in medicine [15]. Some typical clinical applications of X-ray imaging include:

X-ray imaging is a widely used medical tool that has a variety of applications. It is commonly used to examine bones for signs of fractures, dislocations, or other injuries. It can also detect bone diseases such as osteoporosis, osteoarthritis, and bone tumors. In addition to bone imaging, X-ray imaging is also used to evaluate the chest and detect lung conditions such as pneumonia, lung cancer, and emphysema. It can also be used to evaluate the size, shape, and position of the heart and blood vessels. X-ray imaging can also be used to examine the abdominal organs such as the liver, spleen, and kidneys, as well as detect conditions such as gallstones,

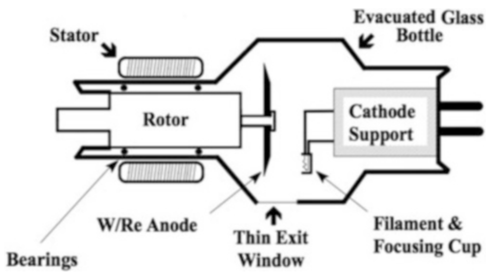

Fig. 2 X-ray imaging principle [14]

kidney stones, and intestinal obstruction. In dentistry, X-ray imaging is commonly used to detect tooth decay, abscesses, and impacted teeth, as well as evaluate the jaw and temporomandibular joint. In emergency departments and trauma centers, X-ray imaging is used to quickly and accurately diagnose injuries such as fractures, dislocations, and foreign bodies. Additionally, X-ray imaging can be used to monitor the progress of treatment for certain conditions, such as monitoring the healing of a fracture or the response of a tumor to radiation therapy.

X-ray imaging, also known as radiography, is a widely used and valuable diagnostic tool in medicine. Some advantages of X-ray imaging include:

X-ray imaging is a popular diagnostic tool because of its wide availability, speed, and low cost. X-ray imaging equipment is widely available in hospitals, clinics, and doctors' offices, making it a convenient and accessible diagnostic tool. Additionally, X-ray imaging can be performed quickly, and results are usually available within a short period of time. Moreover, X-ray imaging is relatively inexpensive compared to other imaging modalities such as MRI or CT. Another advantage is that X-ray imaging produces high-resolution images that can reveal fine details of bone and other internal structures. Additionally, X-ray imaging is a non-invasive technique, meaning that it does not involve the use of incisions or injections, making it relatively safe and comfortable for the patient.

However, there are also some limitations of X-ray imaging to consider:

X-ray imaging has some limitations, one of them being limited tissue contrast. It is not as good as other modalities at distinguishing between different types of tissue, such as tumors and normal tissue. Additionally, X-ray imaging has low soft tissue contrast, meaning it is not as good as other modalities at visualizing soft tissue, such as muscles and organs. Another limitation is that X-ray imaging produces a 2D representation of the 3D structure of the body, which can make it difficult to visualize certain internal structures, particularly in areas that are not easily accessible. This 2D representation can make it difficult to understand some areas of internal structures and make it hard to diagnose certain issues.

7 Computed Tomography (CT) Imaging

7.1 Basic Principles

CT imaging, commonly called CAT scanning due to its use of X-rays to make cross-sectional pictures of the body, is a common medical imaging procedure. The basic principles of CT imaging are as follows:

CT scans use X-rays to create detailed images of internal structures by directing the X-rays at the body from different angles and measuring the intensity of the X-rays that pass through the body with detectors. A special type of X-ray detector called a multi-slice detector is used in CT scans, which can acquire multiple images at the same time from different angles, allowing for the creation of detailed cross-sectional images of the body. To improve image quality, CT scans also use

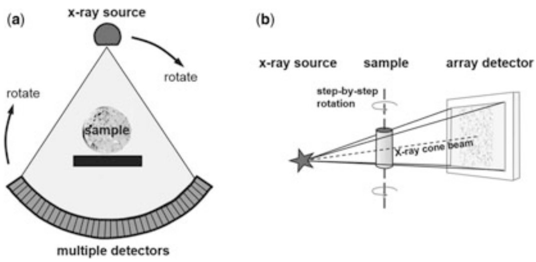

Fig. 3 Computed tomography imaging principle [3]

techniques such as spatial filtering, which removes noise and improves contrast, and multi-energy imaging, which uses different energy levels of X-ray beams to capture different information and increase image contrast. Additionally, CT scans can use a technique called dose modulation, which adjusts the radiation dose according to the size, shape, and composition of the body part being scanned, reducing the risk of side effects. The images obtained from CT scans are then processed by a computer and can be viewed in different ways, such as cross-sectional slices, 3D images, and even virtual reality images [16–18]. CT scans are performed by radiologic technologists and the images are interpreted by radiologists, who are medical doctors who specialize in interpreting medical images (Fig. 3).

A CT (Computed Tomography) scan is a medical imaging technique that uses X-rays and advanced computer algorithms to produce detailed, cross-sectional images of the body. The patient lies down on a table that slides into a donut-shaped machine, called a CT scanner. The X-ray tube, located inside the scanner, rotates around the patient, emitting a series of X-ray beams at different angles [3]. As the X-ray beams pass through the body, they are absorbed by different tissues in varying degrees, creating a pattern of attenuated X-rays. The pattern of attenuated X-rays is detected by an array of detectors located opposite the X-ray tube, which converts them into electrical signals. These electrical signals are then sent to a computer that uses sophisticated algorithms to reconstruct the data into a 3D image.

7.2 Typical Clinical Applications

Computed axial tomography (CAT) scanning, is a medical imaging technique that has a wide range of clinical applications in medicine. Some typical clinical applications of CT imaging:

CT scans can be used for a variety of purposes, including imaging the brain and head for abnormalities such as tumors, bleeding, or trauma. It can also be used to evaluate the sinuses, ears, and eyes. In the chest, CT scans can be used to evaluate the lungs for conditions such as pneumonia, lung cancer, and emphysema. Additionally, it can be used to evaluate the heart and blood vessels. Another specialized CT technique, called CT angiography (CTA), uses contrast material and imaging techniques to visualize blood vessels. This technique can be used to