3D Medical Image Acquisition summary

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Artificial Intelligence & Information Analysis Lab

3D Medical Image Acquisition

- **Introduction**
- 3D Computed Tomography
  - Cone Beam Tomography
  - Micro-Computed Tomography
- 3D Magnetic Resonance Tomography
  - Functional MRI
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  - Diffusion MRI
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Introduction

3D imaging was a revolution in medicine in the late 20th century. Its effect was significant in areas of dentistry such as orthodontics as it helped simplify medical procedures. The philosophy of 3D imaging is based on the collection of 2D images from different angles from which a 3D image emerges. This image is displayed on a screen with the illusion of depth. In this section, various 3D image reconstruction techniques will be developed, as well as the mathematical models used.

Introduction

In relation to 2D imaging, where it is sufficient to obtain slices from the human tissue, 3D imaging requires the use of more complex tools. The two most used tools for 3D image visualization and reconstruction are:

- **Surface Rendering**
- **Volume Rendering**

Introduction

- **Surface Rendering**

This method is used to generate polygonal approaches to the real edges of the image. These edges are called image isosurface. The method used to produce these surfaces is called marching cubes. Also, a way to locate the image boundaries is the thresholding technique.

Introduction

- **Volume Rendering**

This method is widely used for 3D image visualization and reconstruction. Usually, integrates 2D slices in a volume to produce 3D images. So, this technique displays volumetric data as a semi-transparent fog. The data arise from acquiring human tissue from different view angles.

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3D Computed Tomography

The production of (2D) two-dimensional images from the CT scan was an important tool in the hands of doctors until the production of (3D) three-dimensional images of human tissues. As the CT scan has already described, it sends X-rays to the body which, after penetrating the solid medium of the body and sees tissues with different density values. In the following we will describe 2 new types of computed tomography with wide use in dentistry.

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Cone Beam Tomography

- The technique is applied by sending a circular radius in the form of a cone. This enables complete scanning of the 360 degree human body part with a single scan. A reciprocating array of detector simultaneously move around the patient’s head [KUM15].

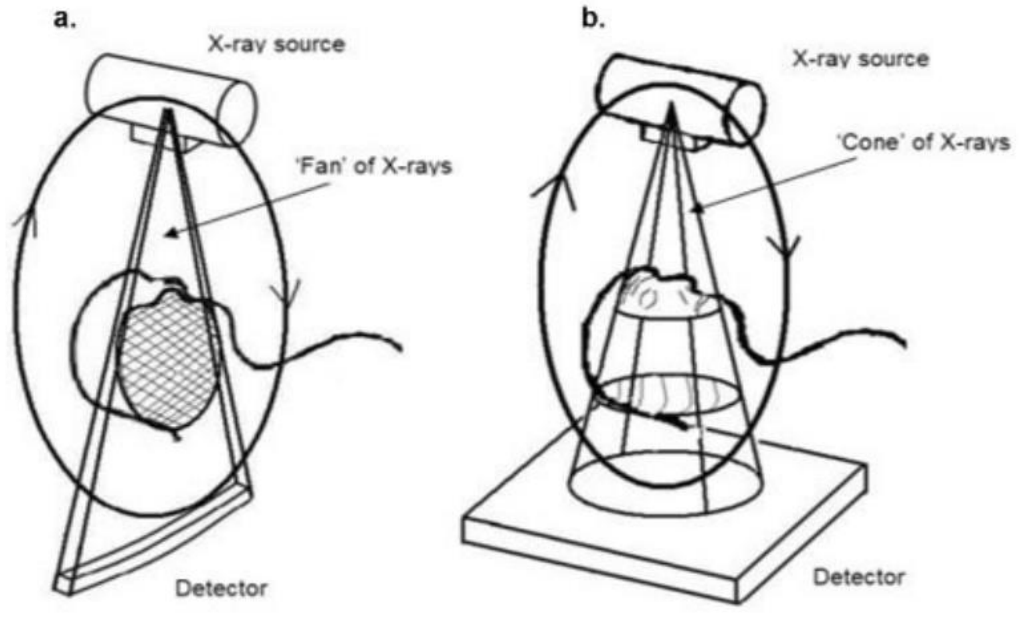

Figure 1.1: (a) Cone-beam CT (b) Geometry [SCA06].

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Micro-Computed Tomography

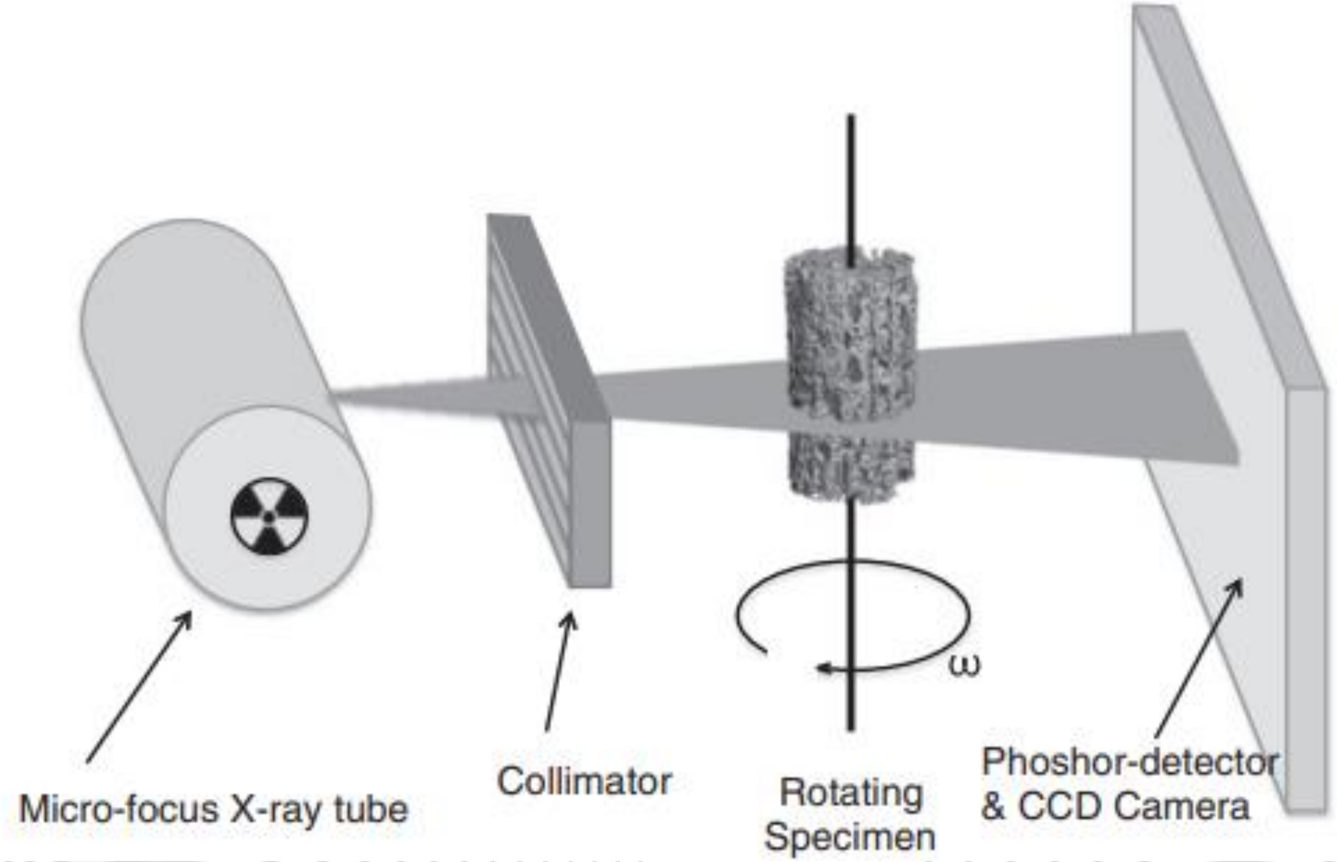

Figure 1.2: Diagram of MCT scanner [BOE14].

Micro-Computed Tomography

- **In the second** case the sample rotates around a table with the source and the detector stationary. The components used in this technique are X-ray lenses or lenses of variable geometric magnification. In this way images with high spatial resolutions are created focusing up to the micrometer scale for some organs and tissues [OSU18].

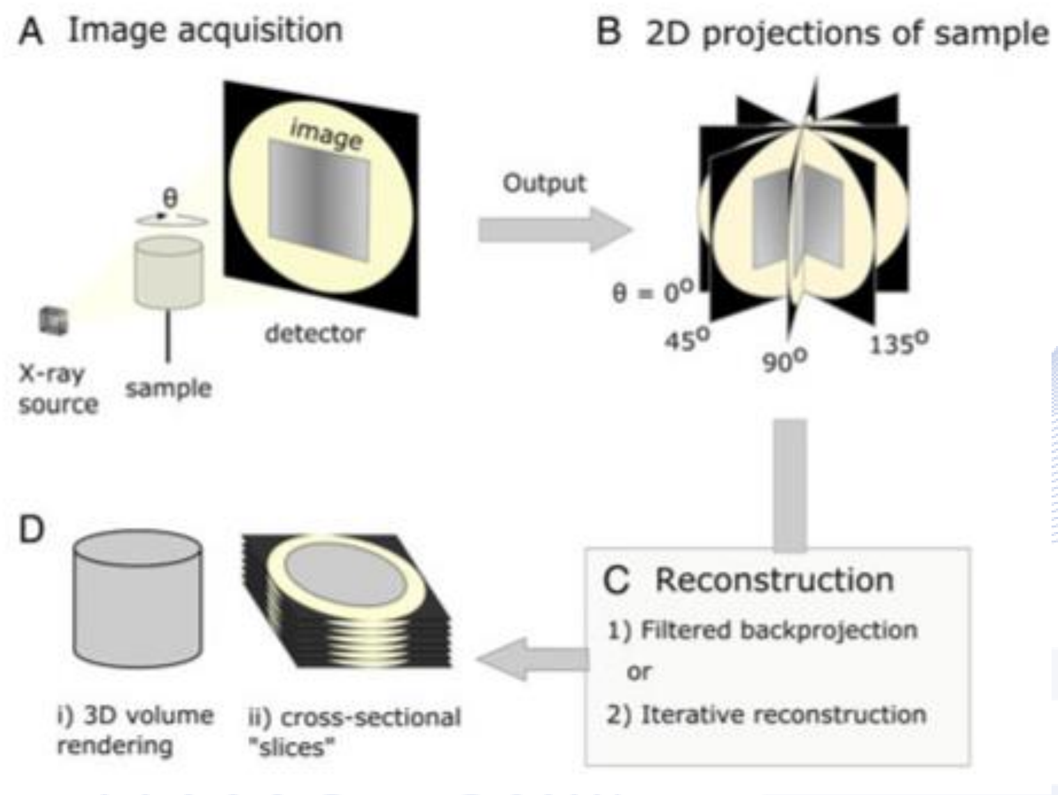

Figure 1.3: Second arrangement of MCT workflow [OSU18].

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3D Magnetic Resonance Tomography

The contribution of two-dimensional imaging to MRI was significant. The representation of the image was done on an axial plane (x-y). This operation was based on a oriented gradient field along the z axis in order to excite an axial slice. It is also possible to use an x-directed gradient to excite a 'Sagittal' slice and a y-directed gradient to excite a 'Coronal' slice. If we combine the three methods, can be produced slices with other orientations [COL16].

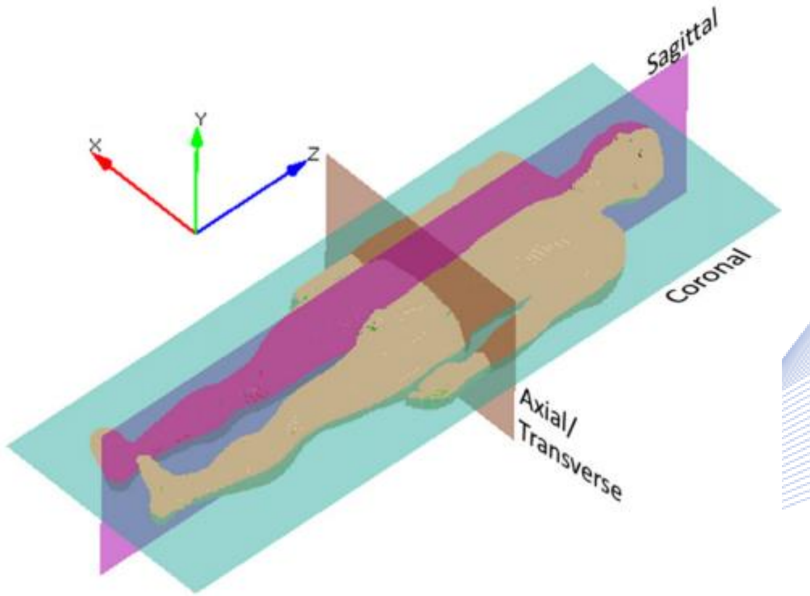

Figure 1.4: Cartesian coordinates along the human body in MRI [COL16].

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Functional MRI

The fMRI is a type of MRI and is extremely useful for mapping the human brain, using many consecutive MRI images. The fMRI scanner measures the transverse relaxation time (T2) which depends on the oxygenation of the brain. This is called Blood Oxygen Level Dependent (BOLD) signal [DEV07].

Functional MRI

The magnetic field orientation pushes tiny single nuclei magnetic signals to be added coherently and produce a large measurable signal. The fMRI records the magnetic signals of the nuclei of hydrogen atoms detected in the bloodstream of the brain [DEV07].

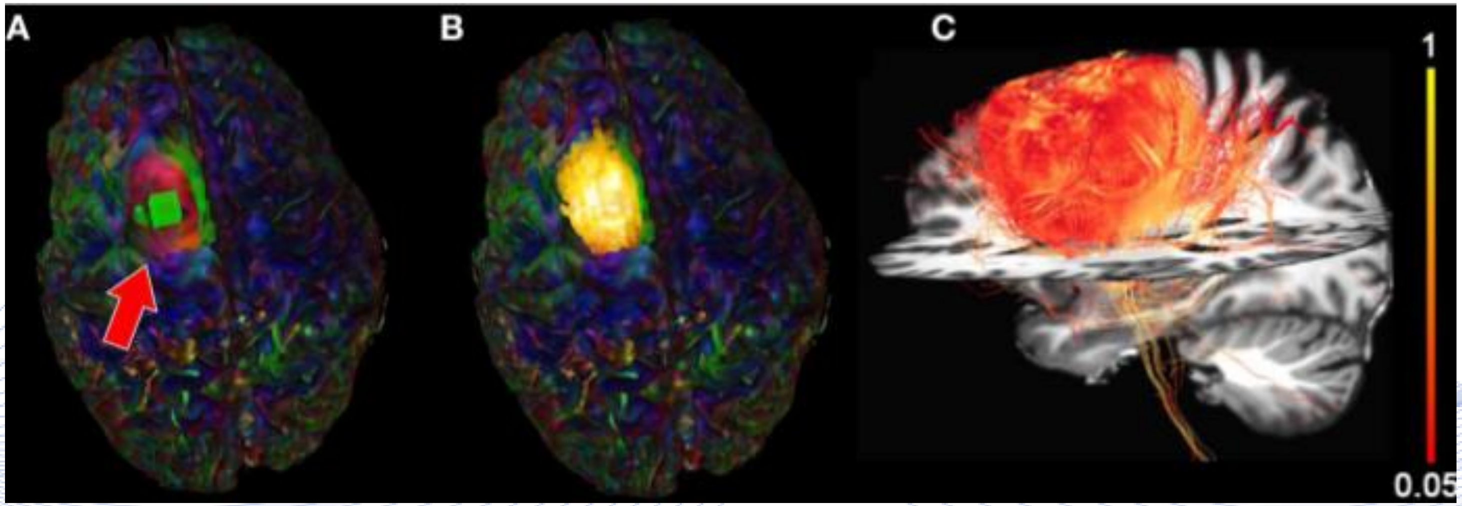

Figure 1.5: Segmentation brain tumor with use of the BOLD signal [CHA15].

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Magnetic Resonance Elastography

Magnetic resonance elastography (MRE) is a non-invasive imaging technique. MRE uses the mechanical waves propagation as a probe to palpate biological tissues. The technique is divided in three categories [LOW16].

1. Tissue Shear-wave production.
2. Displaced tissue encoding in MRI images.
3. Mechanical parameters extraction with the use of dedicated reconstruction methods.

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Diffusion MRI

Diffusion magnetic resonance imaging (dMRI) can represent the complexity of the human nervous system by providing a unique probe of water molecule. Important parts of neural tissue that have been mapped are crossing, kissing and bending fibers [CAB20].

Figure 1.6: The C-shaped connects the hippocampus with the hypothalamus [GAR14].

Diffusion MRI

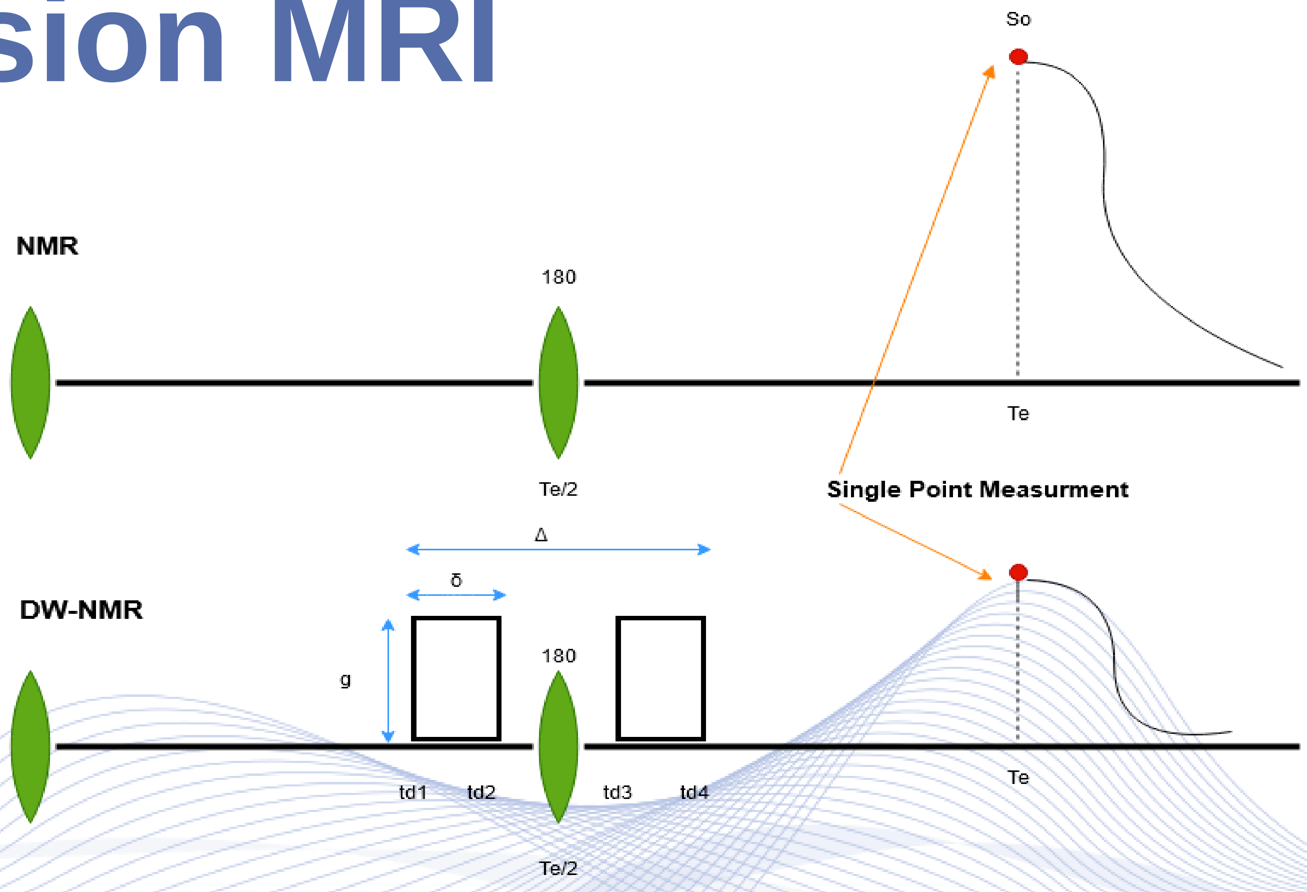

Figure 1.7: A spin echo experiment appears at the top. Down we see the Diffusion sensitizing gradients which are placed between the 180^o radio frequency (RF) pulse. The values δ and Δ are the duration and the separation of the pulses respectively. The value Te is the echo time. The measurement is the maximum that describes the attenuation of the single point.

Diffusion MRI

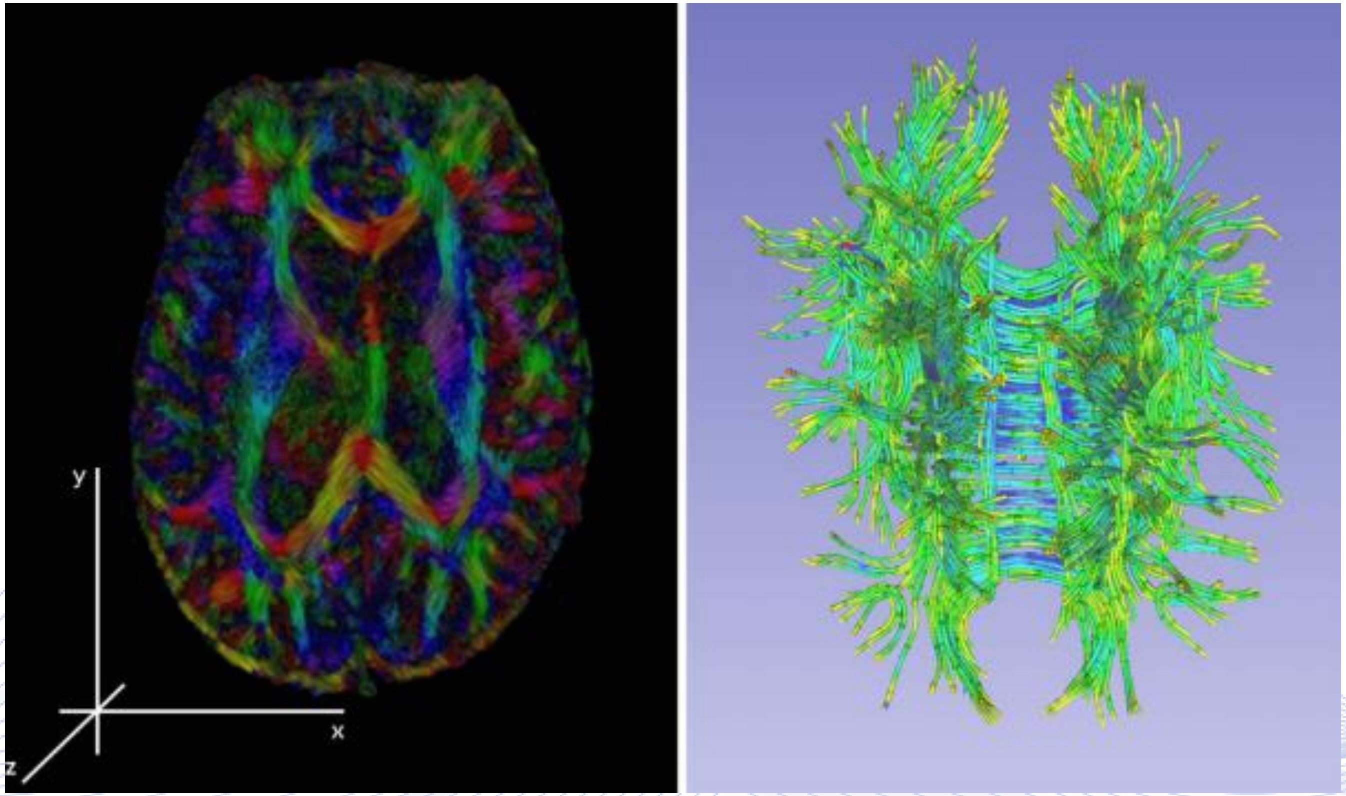

Figure 1.8: **Left**: Diffusion tensor imaging after 3D reconstruction. **Right**: Post-processed image of 3D DTI reconstruction from the DWI sources [GEN18].

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3D Ultrasonography

3D ultrasound imaging is a new approach that is rapidly achieving big use with numerous applications. Figure 1.9 shows the basic principle of an ultrasound system. Transducers focus ultrasound waves along scan lines in the region of interest. It is mentioned that these systems operate in frequencies greater than 20 kHZ. In principle, the ultrasound system focuses sound waves along a scan line that they are constructively superimposed onto the desired focal point.

3D Ultrasonography

As sound waves propagate towards the focal point, they are reflected at any object encountered along their propagation path. The generated sound waves from the transducer become sensors that detect any reflected sound waves. These waves created when the transmitted ultrasound waves encounter a tissues density change within the region of interest. The amplitude of the reflected sound waves forms the basis for the ultrasound image at this focal point location.

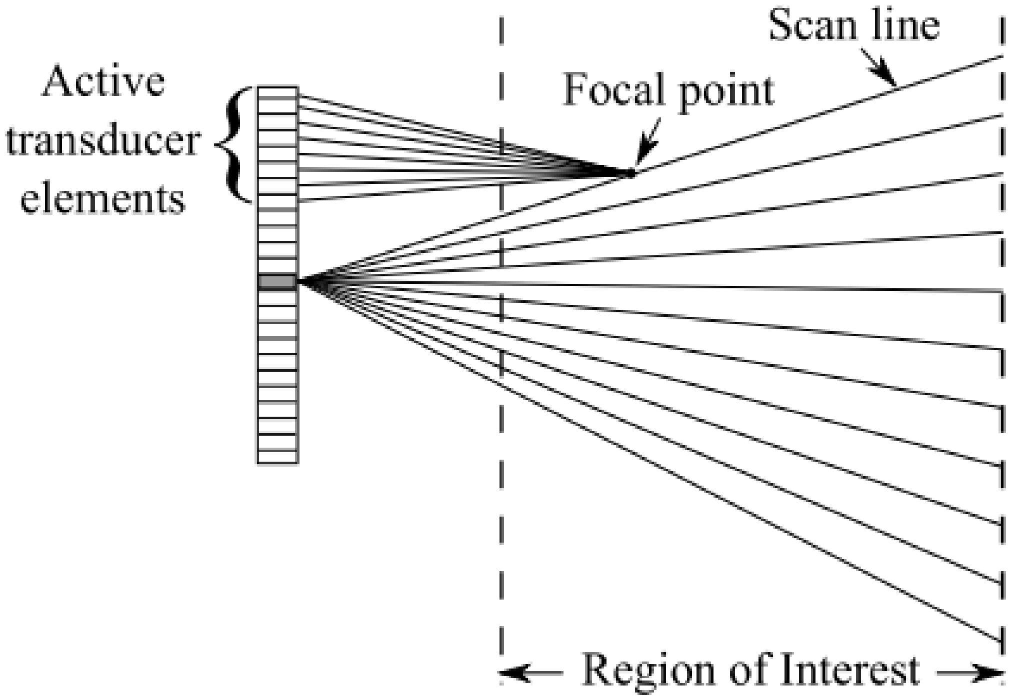

Figure 1.9: Ultrasound basic principle.

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3D Nuclear Tomography

The distribution of radiotracers in the Emission Tomography is done with two basic optical means: projection imaging and tomography. As a projection we call an image that is seen by an observer. The observer is placed outside the body and looking through it. Moreover, a tomographic image is a picture of a cross-sectional slice of the body [WER04].

3D Nuclear Tomography

In modern Emission Tomography imaging systems, projections are acquired for many different slice planes (Figure 1.10), thus allowing a 3D radiotracer distribution $f(x, y, z)$ to be constructed [WER04].

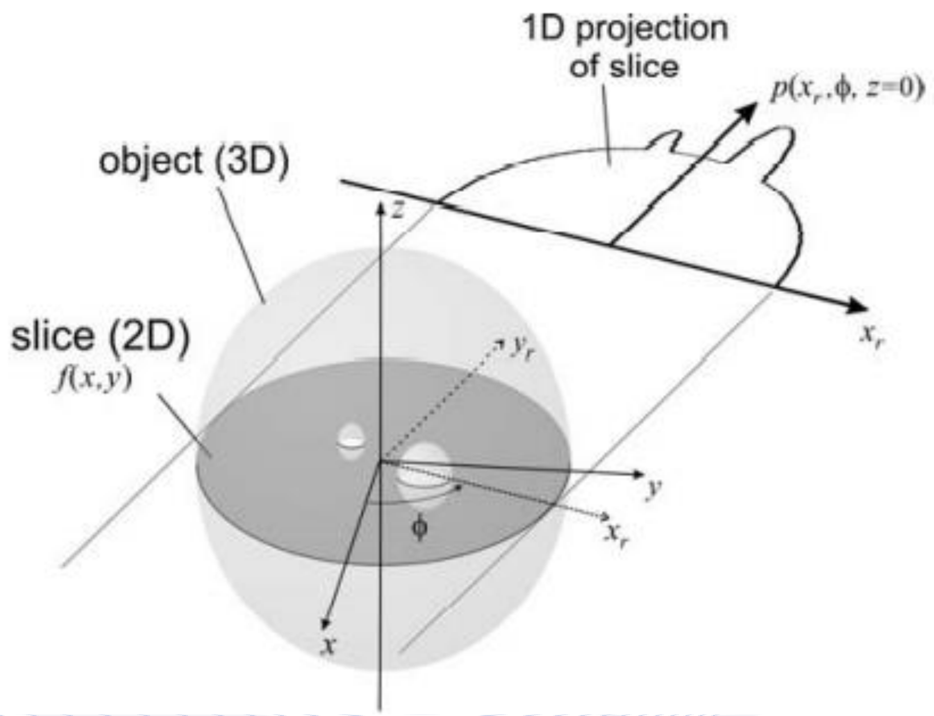

Figure 1.10: 1D parallel projection of 2D slice through an object [WER04].

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SPECT

- **Basic Principle**

The procedure starts by administrating a γ-emitter pharmaceutical substance by an external device. Next, the gamma camera, detects the radioactivity stemming from the body, from 1 or several angles of views. After, from the 3D distribution projection an image is obtained on the 2D detector. The 3D dataset of γ-emitter distribution is obtained in SPECT by piling up many slices usually reconstructed independently [BRU02].

SPECT

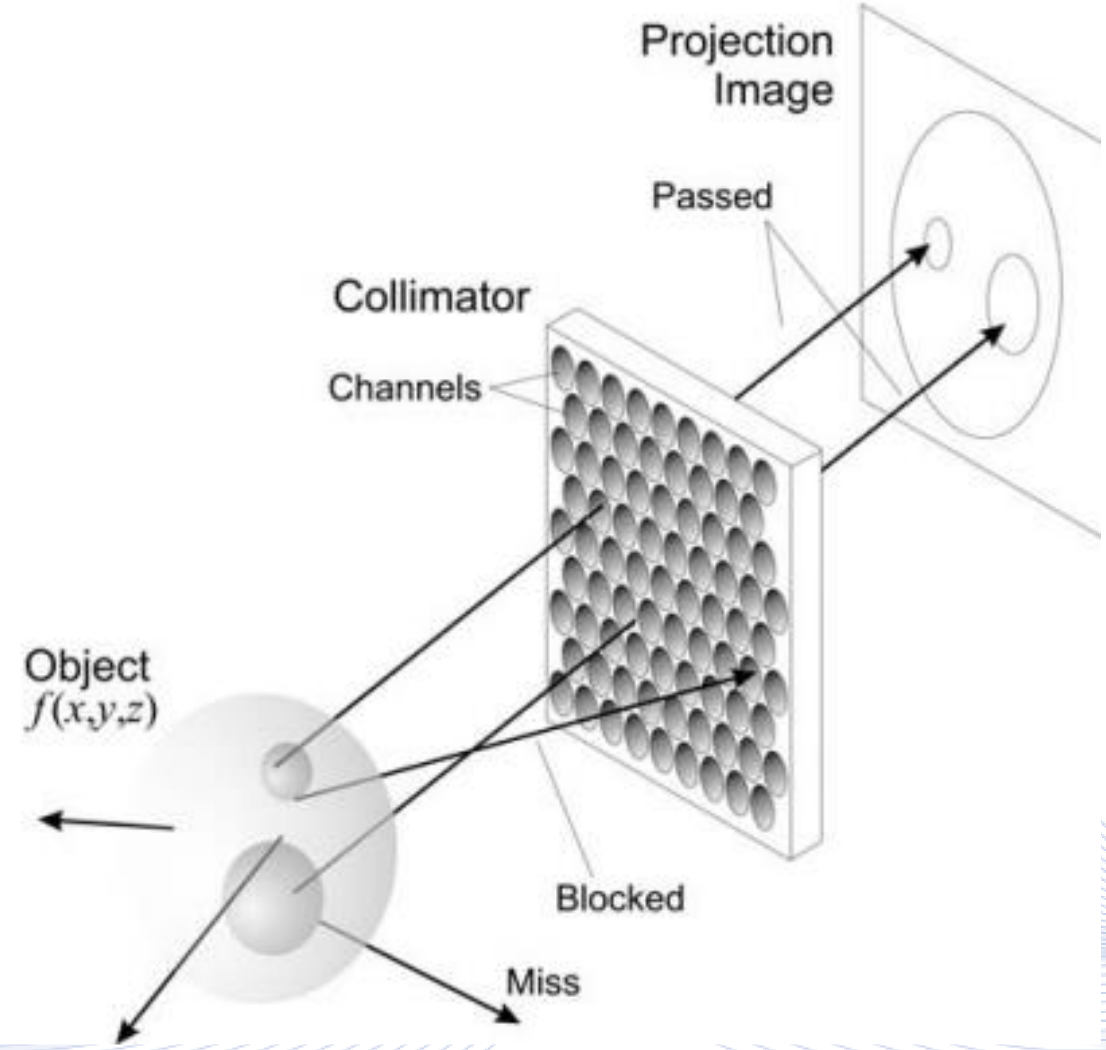

Figure 1.11: The image is formed in Collimator [WER04].

SPECT

- **Basic Principle**

Technetium-99m is one of the most widely used radioisotopes in nuclear medicine. The technetium-99 generates from the emission of gamma rays (photons). Their energy equals to 140.5 keV [LIV12].

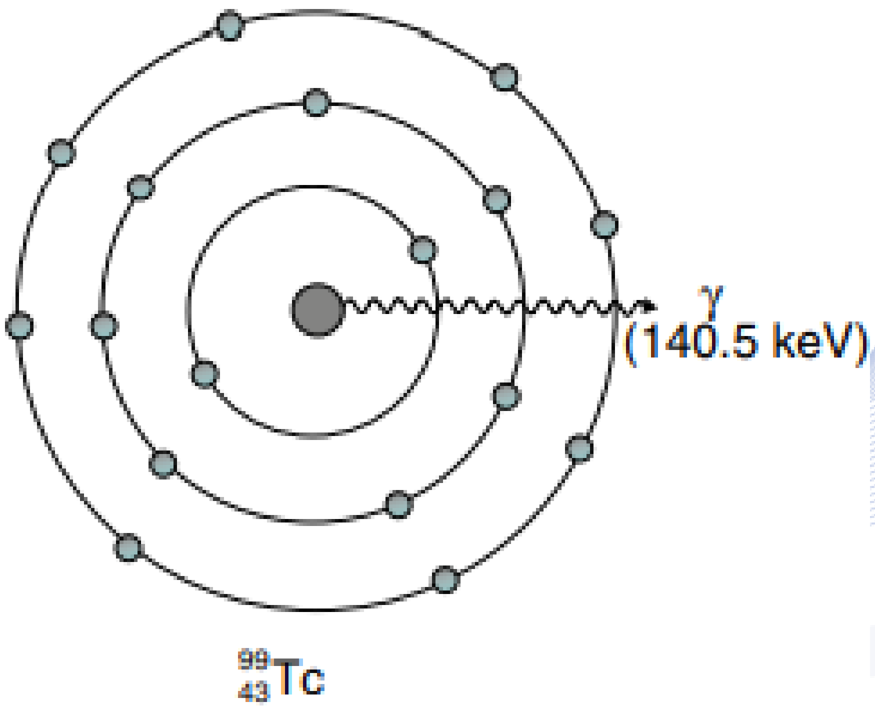

Figure 1.12: Technetium production diagram [LIV12].

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PET

- **Basic Principle**

PET is different from SPECT. PET uses positron emitting radioisotopes instead of single-photon emitters that are used in SPECT [WER04].

The main measurement in PET is the detection of the two photons. These photons are generated from a positron annihilation based on coincident detection of the two photons by two opposing detectors [LIV12].

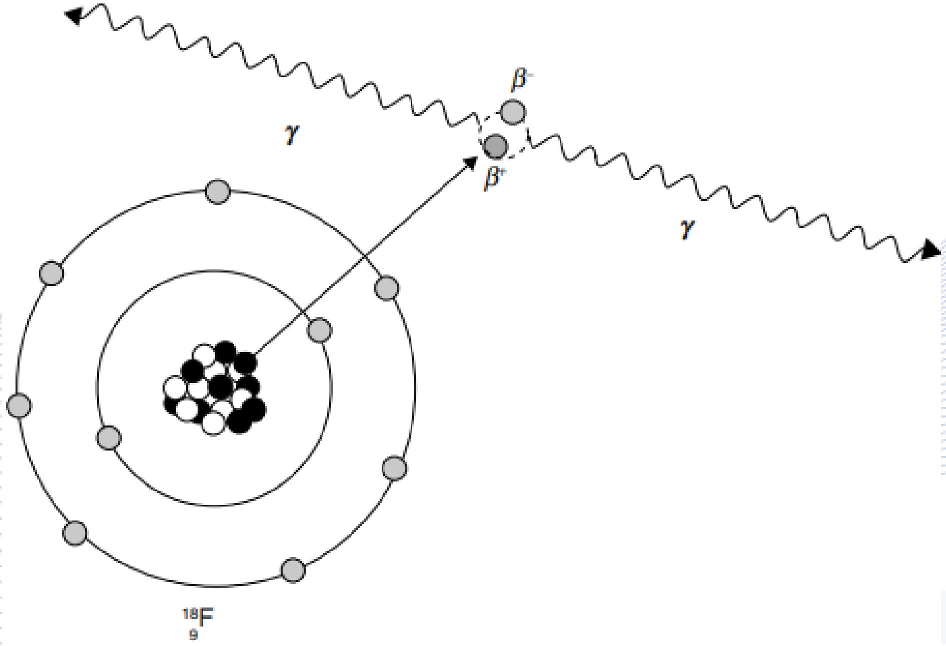

Figure 1.15: Positron radioisotope annihilation [LIV12].

PET

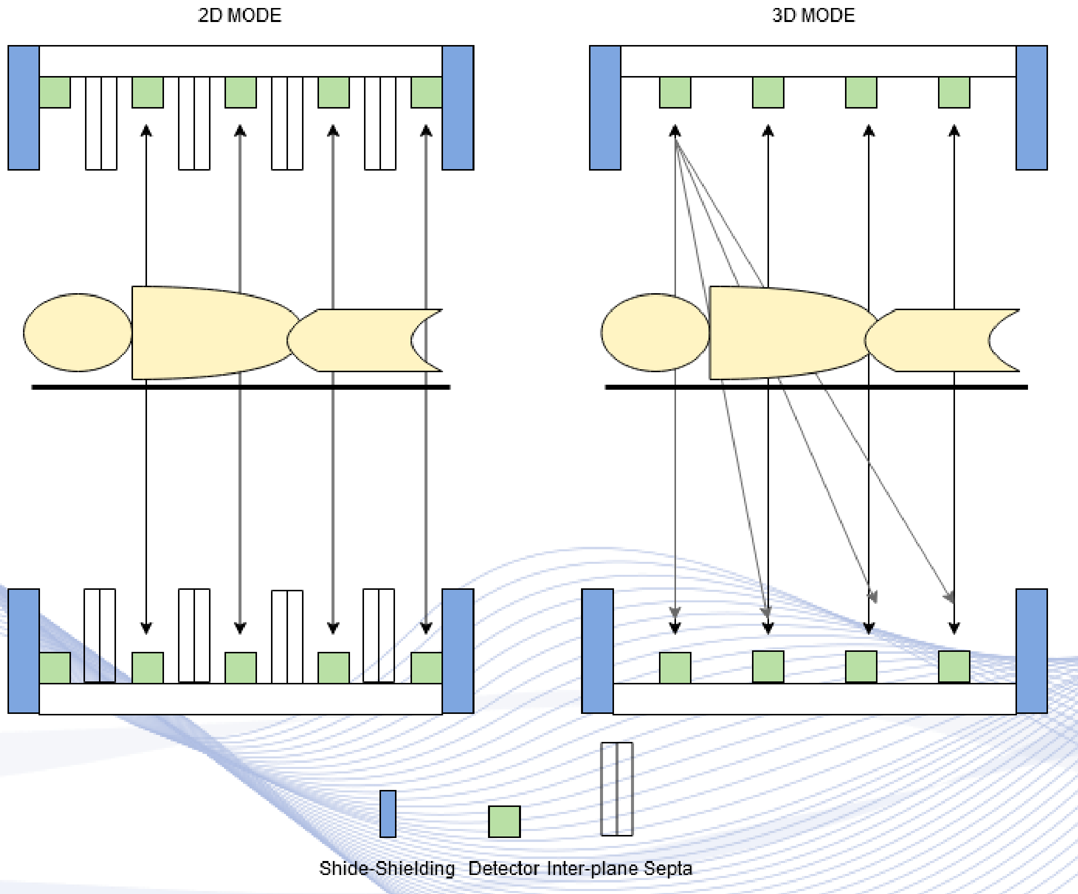

Figure 1.16: Diagram of PET scanner in 2D and 3D acquisition modes.

The detection of photons in PET is similar to the scintillation process in a gamma camera. Annular shielding (septa) may have been placed between detector rings in order to restrict detection of annihilation photons. The removal of septa gives the advantage of producing and acquiring 3D images [LIV12].

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Magnetic Particle Imaging

The main goal of MPI is to reconstruct the spatially dependent concentration of particles. Many different spins take measurements in which potential differences are generated by the linear response of the particles. This response is caused by the application of an external magnetic field. The image is reconstructed by measuring the values of the potential difference (voltage) [KLU18].

The special characteristics of SPIONs are important tools for this type of scan. These special characteristics result from exposure to magnetic fields generated by the coils of the MPI devise.

Magnetic Particle Imaging

The application of direct current and alternating to the coils causes the production of various magnetic fields such as static (Figure 1.18).

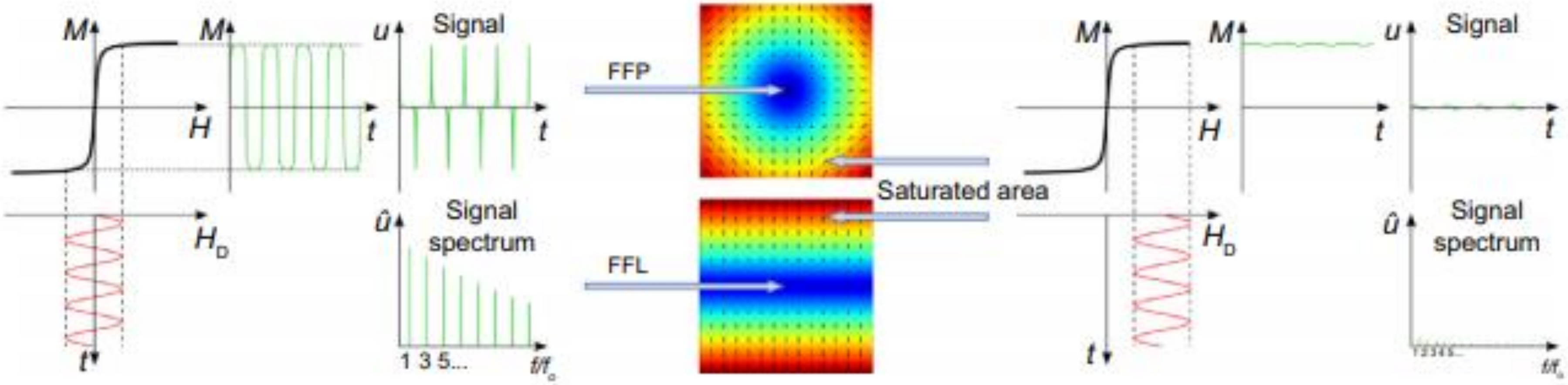

Figure 1.18: Concept diagram of MPI [PAN15].

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Photoacoustic Tomography

Photoacoustic Tomography (PAT), otherwise optoacoustic tomography is a 3D method of medical imaging. This method is based on the photoacoustic phenomenon (PA). Although this phenomenon has been described at the beginning of the last century, its application in medicine has taken place in the last decade. PAT is one of the rapidly evolving techniques of medical imaging.[ZHO16].

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Non-Contact 3D Surface Imaging

Non-contact 3D surface imaging systems selected mainly for capturing quantitative information about the facial soft-tissue. Also are more compassionate in relation with traditional anthropometry.

The advantages of these systems are as follows: they receive data in less than 1 second, they have low invasiveness by archiving the received data for later analysis. Also, these systems are an ideal choice for the representation of 3D images after many studies [HEI10].

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Structured-light scanning (SLS)

The Structured Light method reconstructs 3D images of surfaces based on triangulation. One or multiple illumination patterns are projected onto a scene and observed by a camera. The basic idea of this method appears in Figure 1.19 [SCH12].

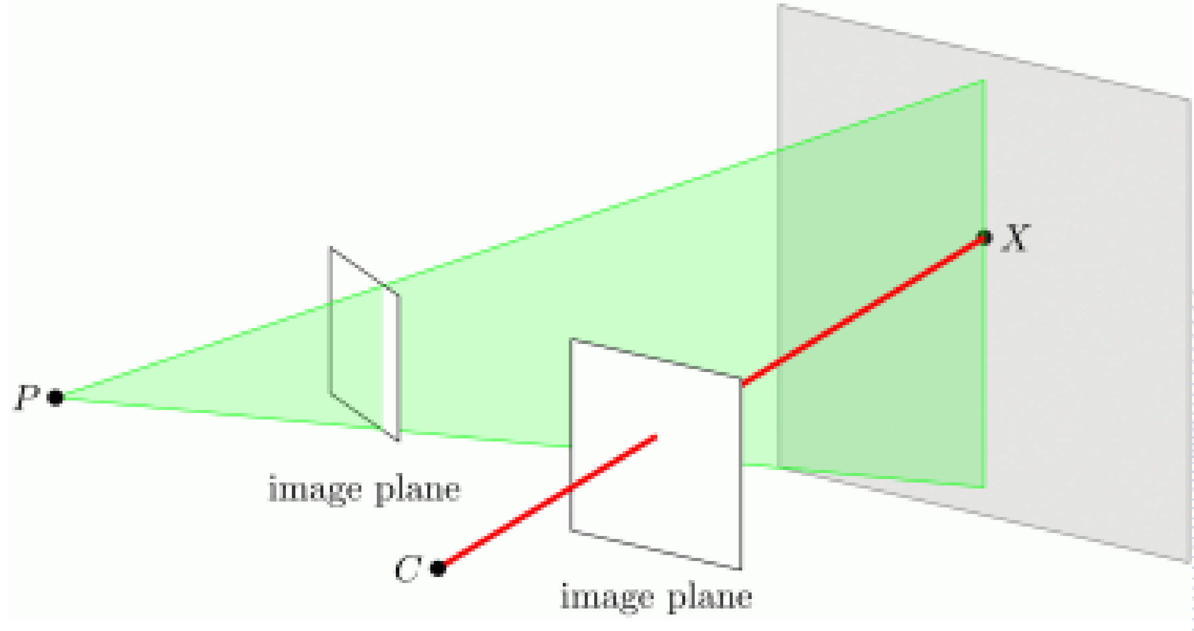

Figure 1.19: Active Triangulation principle [SCH12].

Structured-light scanning (SLS)

The procedure does not require the movement of the individual members as a single static pattern is displayed. As shown in the Figure 1.20, this model uses a color ring of single-shot. This type of pattern is detected in the camera image and yields relatively many 3D points per frame [SCH12].

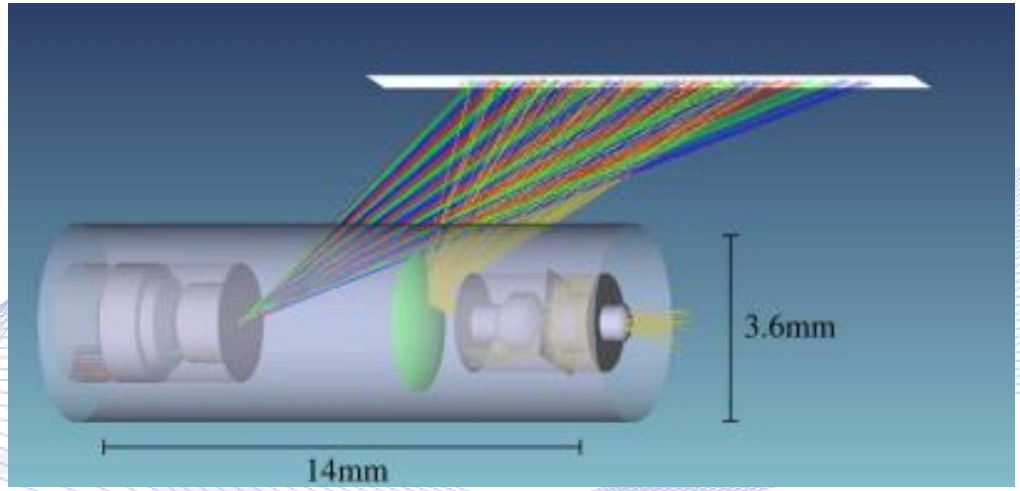

Figure 1.20: SLS Camera setup [SCH12].

Structured-light scanning (SLS)

- **Project Calibration**

Projector calibration results from modeling the projected rings as light ones. A planar dot grid calibration target is acquired in several poses while the ones are being projected. A plane in space is determined by a target surface for each pose. The locations of the dots as observed by a calibrated camera calculates this plane [SCH12].

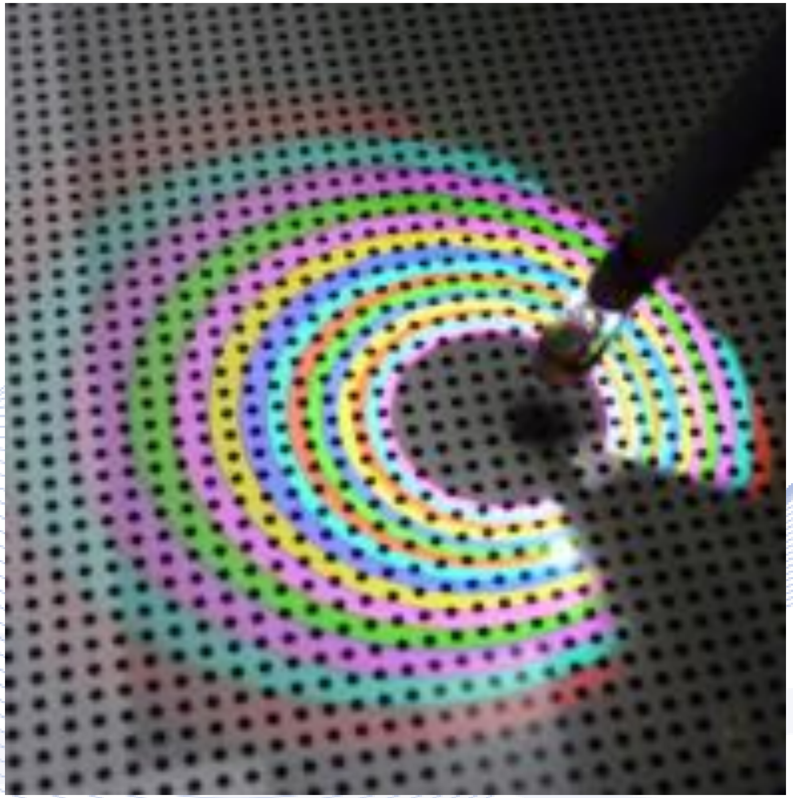

Figure 1.21: SLS and grid board [SCH12].

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Stereophotogrammetry

- **Basic Principle**

In this section we study the contribution of 3D photography to medical diagnosis. The use of 3D cameras and specialized software seems useful in assessing objective and quantitative evaluation of volume changes in Infantile hemangiomas (IHs) [HER14].

Stereophotogrammetry

A 3D stereophotogrammetric camera setup was used (3d MDface System, 3dMD Ltd., Atlanta, GA). We take 3D photos of the patients at the start of propranolol treatment (T0) and at the first control visit (T1). The camera setup consisted of two pods, each equipped with three digital cameras and a flash [HER14].

Figure 1.22: Three-dimensional camera setup and 3D photograph of a patient with IH [HER14].

Stereophotogrammetry

- **Superimposing Images**

After taking the difference of the photos, we find the Infantile hemangiomas region (Figure 1.23) [HER14].

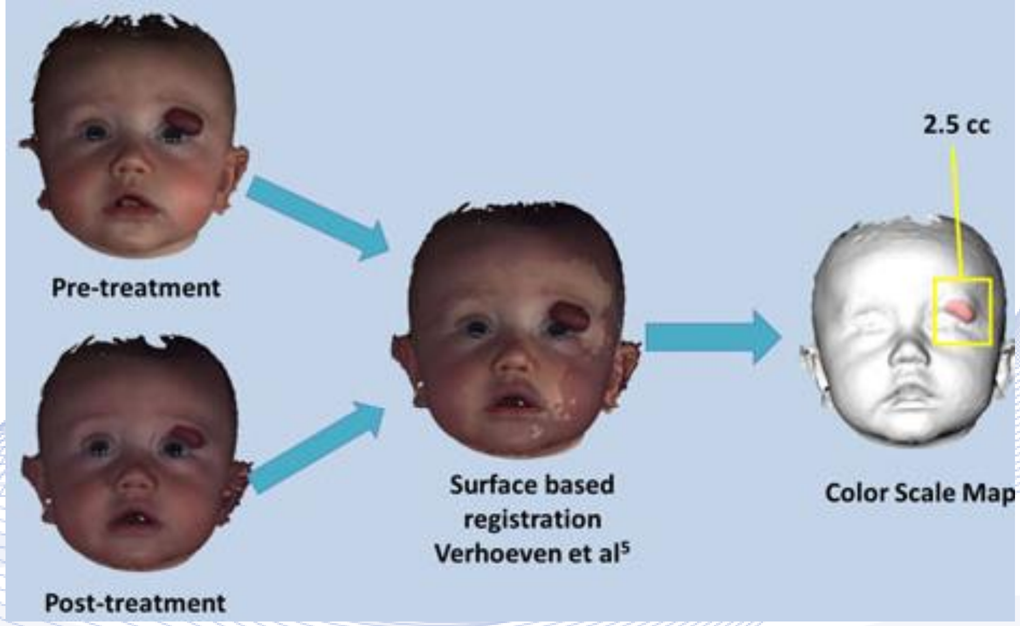

Figure 1.23: Superimposed Images [HER14].

Stereophotogrammetry

- **Mirroring Images**

End by subtracting the volumes from the end of the treatment and those of the beginning, we observe the first positive results (Figure 1.24) [HER14].

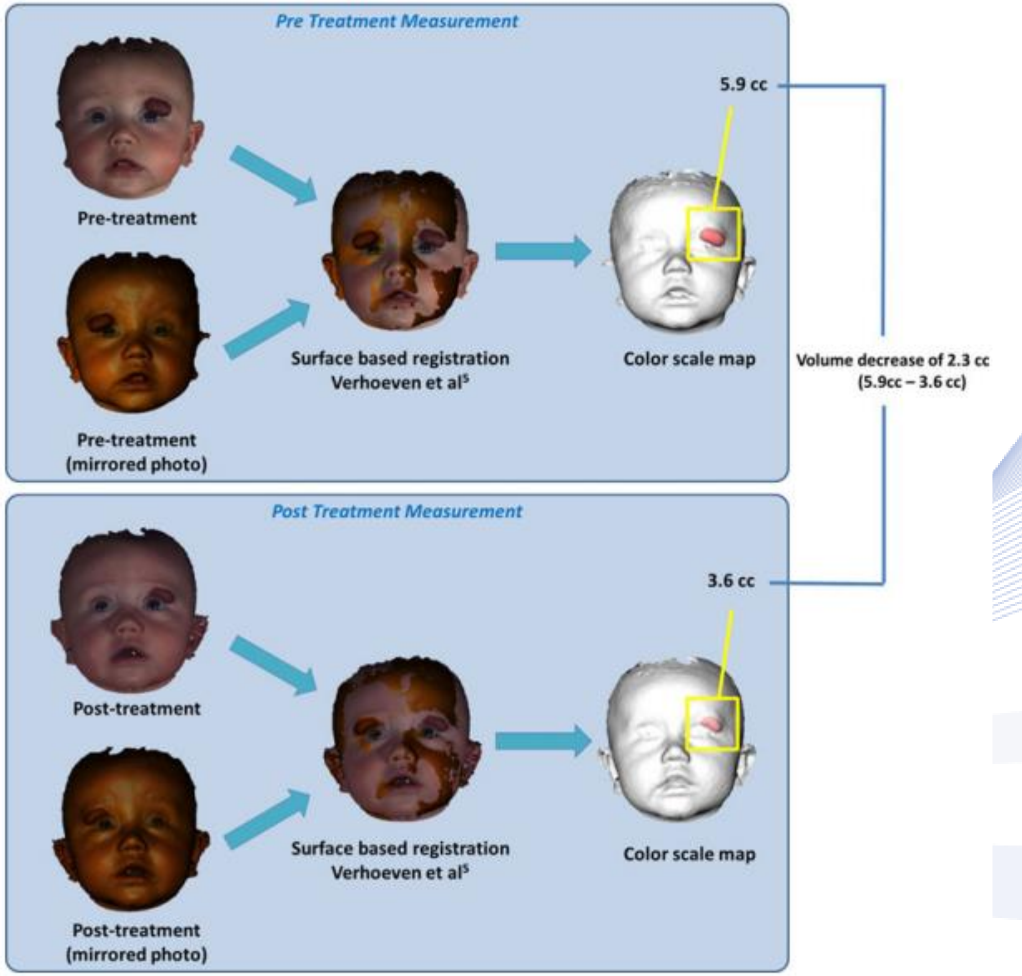

Figure 1.24: Reflecting Images [HER14].

3D Medical Image Acquisition

- Introduction
- 3D Computed Tomography
  - Cone Beam Tomography
  - Micro-Computed Tomography
- 3D Magnetic Resonance Tomography
  - Functional MRI
  - Magnetic Resonance Elastography
  - Diffusion MRI
- 3D Ultrasonography
- 3D Nuclear Tomography
  - Single-Photon Emission Tomography (SPECT)
  - Positron Emission Tomography (PET)
- Magnetic Particle Imaging (MPI)
- Photoacoustic Tomography (PAT)
- Non-contact 3D Surface Imaging
  - Structured-light scanning (SLS)
  - Stereophotogrammetry
- **3D Medical Optical Imaging**
  - Diffuse Optical Tomography
  - Optical Coherence Tomography
  - Confocal Laser Scanning Microscopy (CLSM)

3D Medical Optical Imaging

Medical applications such as microbiology, colonoscopy and other endoscopies require the use of electromagnetic radiation emitted in the visible spectrum. However, with the development of technology the excitation spectrum can be extended beyond the visible. Such spectra are soft ultraviolet 400nm or the near infrared 700nm [DHW10].

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Diffuse Optical Tomography

- **Basic Principle**

Diffuse reflectance images are formed by backscattered diffused light. The data contained in these photographs concern absorption and dispersion by different chromophores and biological structures in the medium. The acquired images are an important source of information for divisive reasons even though they are raw [DHW10].

Diffuse Optical Tomography

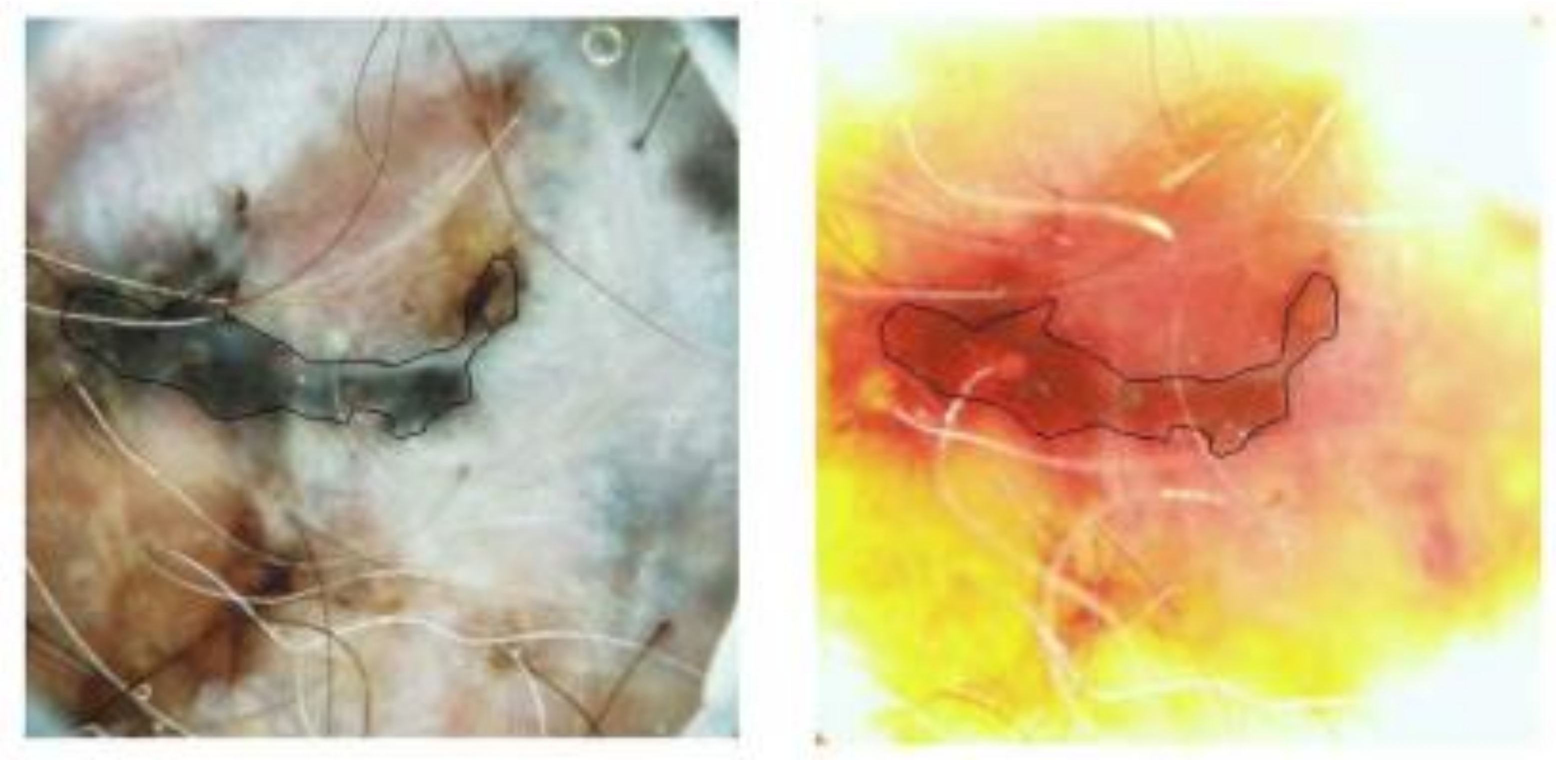

Figure 1.25: Epi-illuminance light microscopy (ELM) image (a) Skin melanoma with a backscattered diffuse reflectance based transillumination image (b) acquired by the Nevoscope [DHW10].

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Optical Coherence Tomography

OCT was discovered in the late 20th century and continues to evolve to this day as an important tool in 3D medical imaging. In an OCT system, light with a low coherence length is divided into two parts. One part serves as a reference while the other penetrates the tissue [DHW10].

Optical Coherence Tomography

The light passing through the tissue interface with a different refractive index thus causing the reflection of light. This reflectance is subsequently mixed with the reference. The coherence occurs when the optical path length difference between the reference light and the reflected light is less than the coherence length [DHW10].

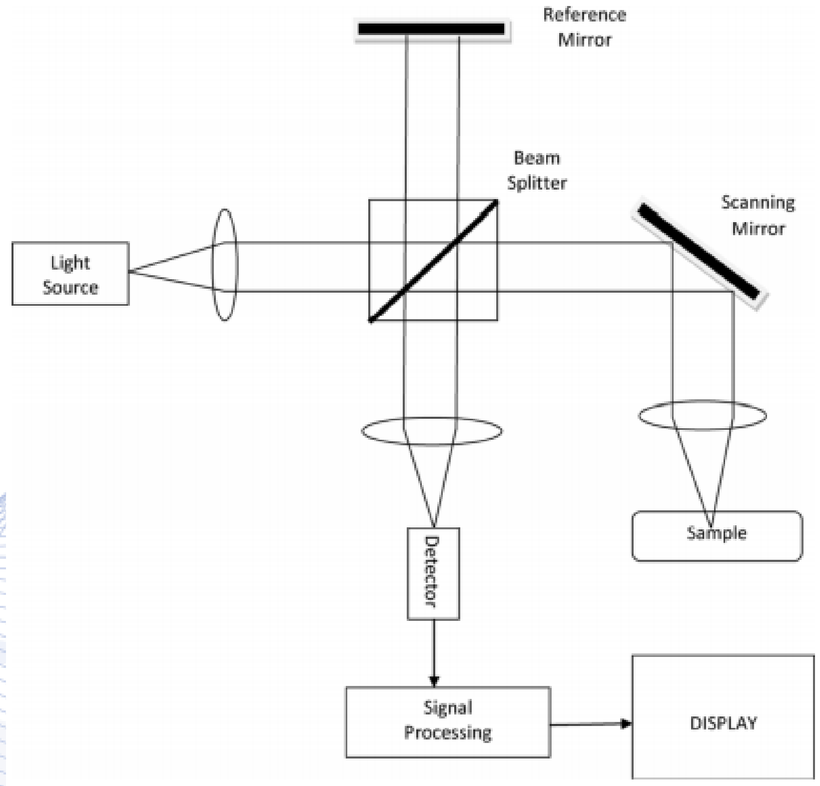

Figure 1.26: Full field Optical Coherence Tomography [DHW10].

Optical Coherence Tomography

The setup of OCT typically includes an interferometer with a low coherence, broad bandwidth light source. Light splits into and recombined from reference and sample arm, respectively [DOU19].

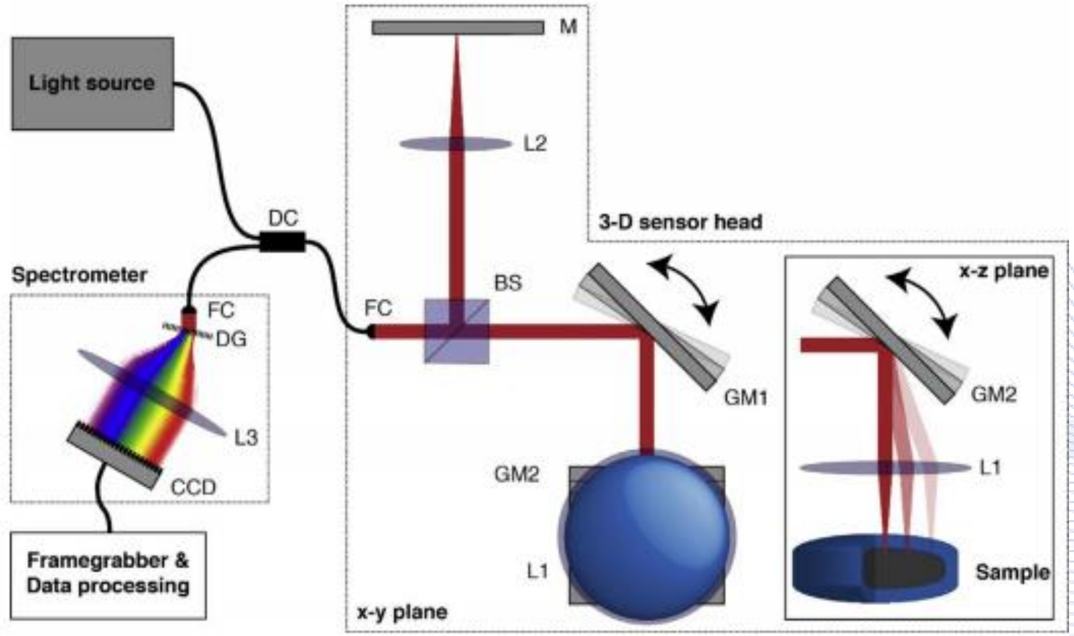

Figure 1.27: Schematic diagram of Optical Coherence Tomography sensor [MAR18].

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Confocal Laser Scanning Microscopy

Confocal microscopy (CM) achieves optical sectioning by a pinhole. This pinhole is located at the focus point before the detector. The pinhole blocks all but the in-focus light from the imaging plane from reaching the detector (Figure 1.28) [DHW10].

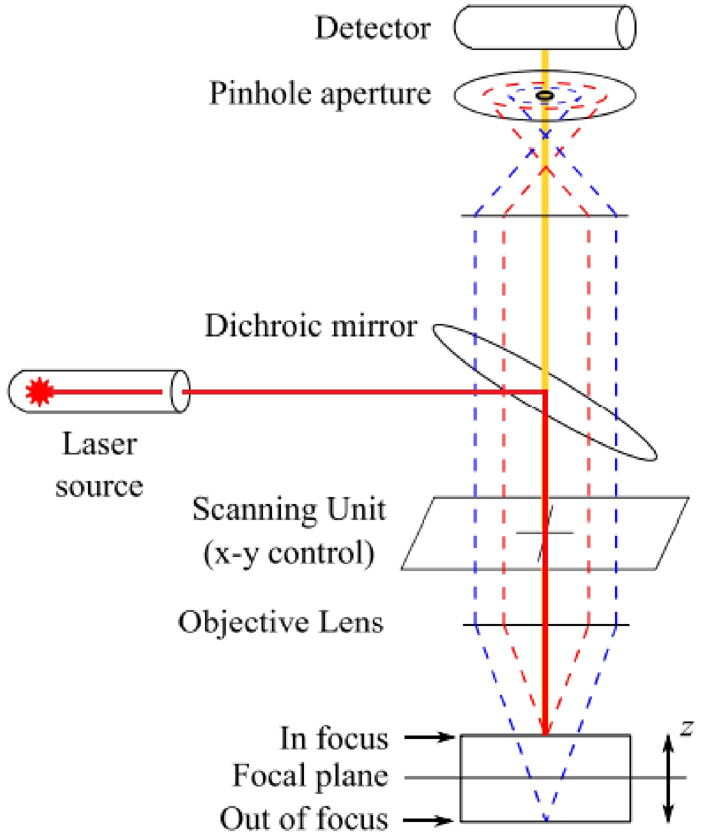

Figure 1.28: Schematic of confocal microscope principle

Confocal Laser Scanning Microscopy

- **Image Reconstruction**

Confocal microscopes use the shape from focus method to perform 3D microscopy and recover the 3D object shape. Single wavelength light is used to archive focus only at a specific object depth. A volumetric image of the 3D object can be generated by putting the optical section at the corresponding section of a 3D image volume.

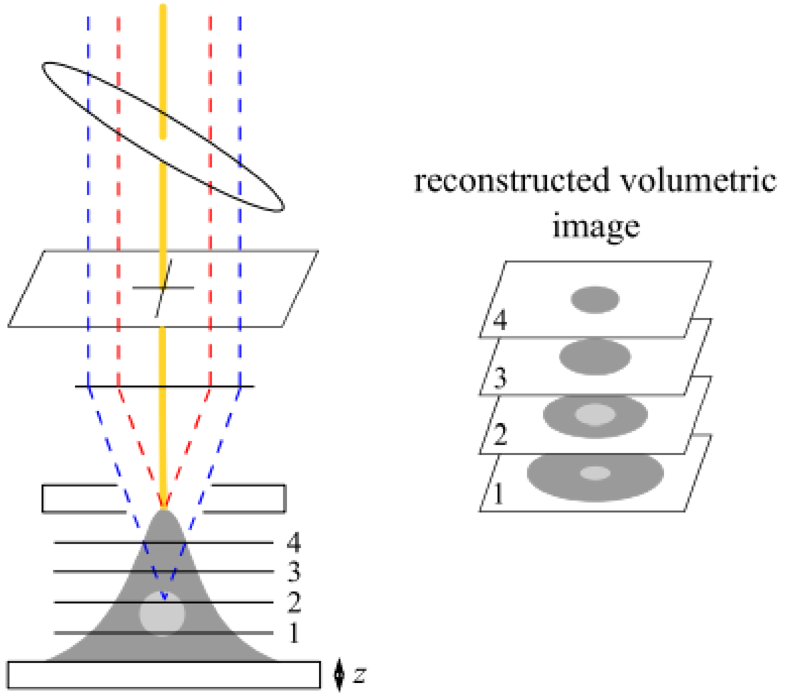

Figure 1.29: Optical Sectioning

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Q & A

Thank you very much for your attention!

More material in
http://icarus.csd.auth.gr/cvml-web-lecture-series/

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