LECTURE 7

TOPIC: BIOPHYSICAL PRINCIPLES OF X - RAY COMPUTED TOMOGRAPHY
TIME: 2 HOURS

Computed Tomography (CT) - is in a medical use the diagnostic tool for many applications, from cancer diagnosis to trauma to osteoporosis screening.

HISTORICAL REVIEW

CT was invented in 1972 by two scientists Godfrey Hounsfield from Great Britain and Allan Cormack from United States. CT was the first modern imaging modality that made it possible to probe the inner depths of the body, slice by slice. The first CT scanner, an EMI Mark 1 produced images with 80 x 80 pixel resolution (3 mm pixels) and each slice required approximately 4.5 minutes of scanning time and 1.5 minutes of reconstruction time. CT is the technology that was made possible by the invention of computer. Modern computers deliver the computational power that allows the reconstruction of the image data vittually in real time. The invention of the CT scanner earned Hounsfield and Cormack the Nobel prize for medicine in 1979.

ACQUISITION

The purpose of the CT scanner is to acquisite a large number (100 - 1200) of CT projections around the patients.

The tomographic image is a representation of a slice of the patient where X - rays were incident. The two - dimensional CT image corresponds to a three - dimensional section of the patients, meaning with CT, three dimensions are compressed into two. The two - dimensional array of **pixels** in the CT image correspond to an equal number of **voxels** in the patients.

pixels - (short for picture elements)

voxels - (volume elements)

The final projection data can be displayed as an image and this is **sinogram**

sinogram - (two - dimensional image from the set of one - dimensional data)

CT "GENERATORS"

1. First generation: rotate/translate, pencil beam

CT scanners represent a diverse cadre of technologies, from computers, motor control systems, X - ray detector design and X - ray tube.

The first generation of CT scanners was a rotate/translate, pencil beam system

This system used paraller ray geometry - starting at a particular angle, the **X ray tube and detector system** translated linearly across the **field of view (FOV)**, acquiring 160 rays across a 24 - cm FOV , for the projection at that particular angle. When the X - ray tube/detector system was finished with its translation, the whole system was rotated and then another translation translation was used to acquire the next projection set. This procedure was repeated until 180 projections were acquired at 1 degree intervals.

There were some problems in addiction to the amount of scan time that the first - generation systems posed. The detector system could not accomodate the huge dynamic range in X ray intensities. The image was not perfect.

One advantage of the first - generation CT scanner was that it accepted only a very small pencil ray of X - rays. The pencil beam allowed very efficient scatter reduction, because scatter that was deflected away from the pencil ray was not measured by a detector.

2. Second generation: rotate/translate, narrow fan beam
The next incremental improvement to the CT scanner was the incorporation of linear array of 30 detectors. The use of 30 detectors increased the utilization of the X ray beam by 30 times over the single detector used per slice in first - generation systems. A relatively narrow fan angle of 10 degree was used. In principle, a reduction in scan time of about 30 times could be expected. However, the whole of this reduction in scan time was not realized because more data (rays and views) were acquired. The shortest time scan with a second - generation scanner was 18 seconds, 15 times faster than the first - generation system. Because there was an increase in the number of rays per view (to 600) and in the number of views (to 540), the image quality improved.

3. Third generation: rotate/rotate, wide fan beam
The translation motion of first and second - generation CT scanners was a major limitation bacause at the end of each translation, the X - ray tube/detector system had to be stopped, the whole system rotated and then the translational motion had to be restarted. The design could never have led to fast scanning (in this situation). The motion of third - generation CT is rotate/rotate, referring to the rotation of the X - ray tube and the rotation of the detector array. It was an evolution, because third - generation scanners could deliver scan times shorter than 5 seconds. That is a difference compared from first and second generation, which were much slower.
The number of detectors used in third - generation scanners was increased (up to about 750 detectors).
The rotate/rotate geometry solved the mechanical problems by removing the translational motion, practical problems remained. The signals from the large number of detectors (about 1000) needed to be conveyed via wires from the rotating gantry to the computer system sitting fixed on the floor. This means that the ribbon cable used to connect the detectors with the electronics that recorded the signal needed to be carefully rolled out from a cable spool as the gantry rotated, and the gantry stopped and began to rotate in the opposite direction, the ribbon cable needed to be retracted. In consequence having the detectors on the moving part of the scanner made problems with cable wear - **ring artifacts** (mistakes in callibration)

4. Fourth generation: rotate/stationary
Fourth - generation CT scanners were designed to overcome the problem of electronic drift between the many detectors used in the system, and therefore this design eliminates ring artifacts due to detector calibration problem. With fourth - generation design, the detectors are removed from the rotating gantry and are placed on a stationary annulus around the patients. Because of the detectors are stationary, the wires leading them and stationary electronics and computer system is stationary too.
Modern fourth - generation CT systems use from 1200 to 4800 individual detectors. Because the X - ray tube still rotates but the detectors are stationary, this generation uses a rotate/stationary motion.

There is a difference in detecting in use of third and fourth generation scanners.

DETECTOR TYPES

Most modern CT use either **Xenon detectors** or **solid - state scitillator ectors**

The Xenon detectors use high pressure (about 25 atmospheres) gas between two ionization plates. Xenon detectors need to be placed in a fixed orientation with respect to the X ray source, because of their high directionality. This means that Xenon detectors cannot be used in fourth - generation CT and are only used for third - generation.

Solid - state detectors are made of scintillator materials, which emit visible light when struck by X rays. This emitted light is collected by a photodiode, an electronic device that converts light into an electrical signal. These detectors are for fourt - generation CT.

5. Fifth generation: stationary/stationary

A novel CT scanner was developed for <u>cardiac tomographic imaging</u>. This **"cine CT"** scanner does not use a conventional X ray tube but rather a large ring that circles the patients, which lies directly opposed to the detector ring. The X - rays are produced from the focal track as a high - energy electron beam. There are no moving parts to this scanner gantry. The electron beam is produced in a vacuum pumps.

<u>The cine CT is usually used in cardiology. It is capable of 50 - milisecond scan times and can produce 17 CT slices each second for example in heart structures.</u>

6. Helical CT scanners

Besides following types of computed tomography it is distinguished **a helical CT** too.

This design makes it possible to archieve greater rotational velocities than conventional systems, which allows for shorter scan time. It is used <u>a slip - ring technology</u>

<u>THE MAIN COMMERCIALLY AVAILABLE CT SCANNERS</u>

MODEL	SCANNING AND GEOMETRY
Philips T60	rotate/rotate
Picker 1200	rotate/stationary
General Electric 9800	rotate/rotate
Siemens DRH	rotate/rotate
Toshiba 900S	rotate/stationary(slip ring)
Toshiba Xpress	rotate/rotate(slip ring)

RADIATION DOSE

The units of radiation (absorbed) dose are the **RAD - 100 ergs/gram** or preferably in SI units the **GRAY - 1 Joule/kilogram**
The relationship between two quantities:

1 Gy = 100 Rad

TYPICAL DOSES FOR CT

SCAN TYPE	SLICE THICKNESS	DOSE
head	10 mm	65 mGy (6.5 Rads)
spine	5 mm	23 mGy (2.3 Rads)
body	10 mm	15 - 25 mGy (1.5 - 2.5 Rads)

dose - is a measure of radiation risk

Because the radiation is distributed quite homogeneously in a CT scan and the volume of the irradiated tissue is different with each slice a straight dose between a CT scan and a radiographic procedure is misleading. Probably, the better is an **integral dose**.

integral dose - is a measure of the amount of energy deposited in tissue

Integral dose (joules) = Dose (joules/kg) x Mass of irradiated tissue (kg)

ARTIFACTS IN X - RAY CT
* beam hardening
* partial volume
* motion
* scattered radiation

LITERATURE
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