TELERADIOLOGY AND TELEPATHOLOGY

TELERADIOLOGY

- Radiology is a medical specialty that uses imaging to diagnose and treat diseases within the body.
- It may uses x-rays and other imaging methods for this purpose.
- Teleradiology is the electronic transmission of radiology images from one location to another for the purposes of interpretation and/ or consultation through digital, computer-assisted transmission, typically over standard telephone lines, Wide Area Network (WAN) or a Local Area Network (LAN).
- Teleradiology was the first widely deployed implementation of telemedicine and therefore, it is presently considered as a mature technology.

- The main advantage of teleradiology is that is allows more timely interpretation of radiologic images and gives greater access to secondary consultations and to improved continuing education.

The goals of teleradiology include:

i. Providing consultative and interpretative radiologic services
ii. Providing timely availability of radiologic image interpretation in emergent clinical care situations
iii. Enhancing continuing educational opportunities for practicing radiologists

- Teleradiology is used to include image transfer from all types of modern popular modality covering x-rays, computed tomography, fluoroscopy, and digital subtraction.
- In addition, there are other types of imaging devices such as photography, endoscopy and microscopy which are used for specialized applications.
- Thus the term teleimaging would be a better term to describe the area of image transfer in telemedicine.
- A rapid increase in the use of teleradiology is possible because a number of enabling technologies such as affordable high-speed telecommunication networks and improved data compression techniques needed for teleradiology have matured in recent years.

Types of Imaging Modalities

There are several methods of medical imaging in modern medicine. Each has different potential advantages and disadvantages including exposure to radiation with some types of imaging.

The commonly used imaging techniques are:

X-rays

- X-rays are the oldest and most frequently used form of medical imaging.
- The images are taken by passing x-rays through a part of the body under investigation and recording the amount of x-radiation not received in the body.
- It is a non-invasive medical test that helps physicians diagnose and treat medical conditions.
- From diagnostic and imaging point of view, the resolution of x-ray as 4K x 4K is required to capture the necessary details.

Computed Tomography (CT)

- Computed tomography is another imaging system which also makes uses x-rays.
- CT images are generated by making the patient to lie on a table, which passes through a donut-shaped scanning machine. The x-rays that pass through the patient are digitized and pulsed signals are detected by detectors on the opposite side of the x-ray source.
- An image of the tissue density is computed by the CT scanner and represented as a slice of the patient's body.
- In modern CT scanners, three-dimensional (3D) image can be computed from multiple scans. A CT scan may consist of 10 to 12 individual cross-sectional images.
- These can be laser printed on to high quality transparency film. Each image is a 512x512 data matrix containing 256 shades of gray.

Magnetic Resonance Imaging (MRI)

- MRI is a non-invasive imaging technology based on excitation and detection of the change in the direction of the rotational axis of protons found in the water that makes up living tissues.
- The patient is surrounded by extremely powerful electro magnets which act to align the atomic nuclei in the body.
- When a radiofrequency current in the pulsed form is externally applied to the patient, the protons are disturbed, and spin out of equilibrium. When the radiofrequency field is turned off, the nuclei return to their initial orientation, emit radiation which is picked up by a receiver coil. The analysis of this radiation forms the basis of identifying the concentration of certain atoms within the body and helps in generating an image based on this concentration.
- Image resolution in MRI conforms to 128x128 or 256x128 matrix size.

Ultrasound Imaging Systems

- Ultrasound imaging systems involve passing a high-frequency sound wave (2-4 MHz) into the patients body.
- In an ultrasound examination, a transducer (probe) is placed directly on the skin of the patient’s body or a body opening. A thin layer of gel is applied to the skin so that the ultrasound waves are transmitted from the transducer through the gel into the body. The ultra sound waves get reflected off from various internal body structures of the patient.
- The received ultrasound waves are then amplified, processed and a two-dimensional image of the scanned area is constructed.
- Unlike x-ray imaging, ultrasound imaging does not involve exposure to ionisation radiation. The advantage ultrasound lies in their ability to detect soft tissue, such as tumors and lesions.

- Ultrasound today is the preferred non-invasive diagnostic imaging modality practiced in most of the medical specialties, which include cardiology, internal medicine, obstetrics and gynecology.

Nuclear Medicine Imaging Systems

- Nuclear medicine uses certain properties of isotopes and the energy particles emitted from radioactive material to diagnose or treat various pathological conditions.
- Based on the principle of injecting the patient with a radioactive substance and detecting the gamma rays that are emitted.
- There are three types of machines: These are 9i0 Conventional gamma camera, 9ii0 Single Photon Emission coupled Gamma camera (SPECT), and (iii) Positron emission Tomography (PET).

Gamma camera

- Gamma cameras map the function and processes of the various parts of the body.
- The most commonly used tracer is technetium-99m.
- As the tracer travels through the body it emits gamma radiation. The progress of the tracer in the body is tracked by a crystal that scintillates in response to gamma rays.
- The resulting flash of light is converted into an electrical signal by an array of light sensors which help in constructing the image.
- Functional scans of the brain, thyroid, lungs, liver, gallbladder, kidneys and skeleton are carried out this gamma camera.

SPECT

- SPECT imaging is carried out by employing a gamma camera which acquires multiple 2D images from various angles.
- A computer then performs the tomographic reconstruction by using algorithm to the multiple projections, thus giving 3D dataset.
- Tumor imaging, infection, thyroid imaging, bone scintigraphy and functional cardiac or brain imaging are carried out using SPECT complemented gamma camera.

PET

- It is based on the principle that when positrons are emitted from the radioactive substance, they are destroyed by interaction with electrons.

- As a result two gamma rays travelling in opposite directions are produced after annihilation. when these gamma rays are detected, it is observed that there is slight difference in their arrival times at the detectors.
- The time difference can be used to estimate the position of the emission of the gamma rays, which enables the construction of a three-dimensional image of the organ of the body under investigation.
- A PET is useful in evaluating important body functions such as blood flow, oxygen use, and glucose metabolism, to understand how well organs and tissues are functioning.
- Most nuclear medicine images occupy 128 x 128matrix although for some purposes 256 x 256 matrix with 256 gray levels are used.

Steps involved in teleradiology

(i) Producing digital images: When the output of the imaging device is not available in digital form, the first step lies in digitising.

(ii) Interfacing patient information: Providing the health record information required to correctly identify the patient and his complete medical history to the radiologist

(iii) Compressing images and other data: For quick and efficient transfer of data and images from one site to another, compression is a software technique by which certain pixels in the digitised image are dropped to decrease transmission time.

(iv) Transmission of images: The images are transferred from one to another over telephone lines, ISDN, T1, Ethernet/LAN, satellite or coaxial lines, etc. The choice of the communication method depends file size and bandwidth of line of transmission.

(v) Reconstruction of images: This is done at viewing sit for display, evaluation and review.

Components of a teleradiology system

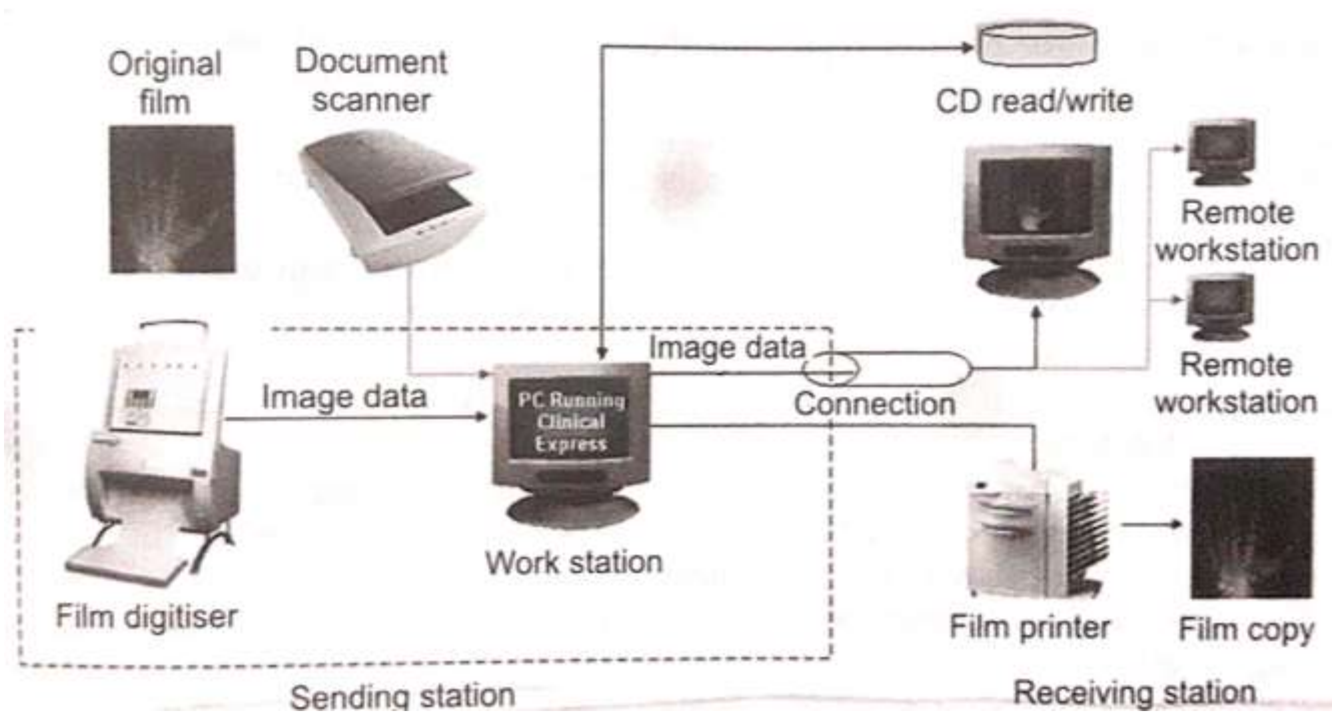
A basic teleradiology system consists of three basic components:

(1) An image sending station

(2) A transmission network

(3) A receiving/image review station

The radiological images are into a digital format at the sending station, sent on the transmission network and received, viewed, and stored at the review station.



Components of a teleradiology system

(1) An image sending station

- It has a telemedicine workstation, film digitisation equipment and a modem.
- Film digitisers can be categorised into three types:
  - (i) Camera digitiser
  - (ii) Charged coupled device (CCD) scanner/digitiser
  - (iii) Laser scanner digitisers
- Once the film digitiser has converted the image to a digital format, the data is sent to the computer and to the modem upon command of the equipment operator. The modem is the control device which converts digital data into electrical impulses that are sent along the transmission network such as telephone lines.

Three important specifications for the teleradiology sending station are resolution, compression, and transmission speed.

Image resolution: Resolution is the ability of the imaging system to differentiate among closely spaced objects.

- As the image is read by the digitiser, the information contained in each pixel is assigned a number. The number represents the amount of density (information) it contains and is called the gray scale (or density) number.
- A higher number is assigned to a pixel that has a lot of information (black) as compared to a pixel with lesser information (white).
- The image resolution is determined by the number of pixels in an image and the range of density of numbers per pixel.
- Typical matrix resolution sizes are 512 x 512, 1024 x1024, and 2048 x 2048.
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- Typical gray scale ranges offered are 256 (8 bits) to 4096 (12 bits) shades of gray.
- With higher resolution the no. of pixels and consequently the file size increases and so does the time required to transmit that file increases.

Compression:

- Data compression is used to increase the transmission speed and reduce storage requirements for a particular size of data file.
- Compression algorithms use a variety of techniques with JPEG being quite popular.
- JPEG is reasonably fast in carrying out both the compression and decompression functions and is widely employed.
- JPEG is the only compression technique permitted by DICOM 3.0.

- Conventional JPEG compression of 10:1 works reasonably well for plain films. However, CT, MR, nuclear medicine and ultrasound imaging systems require higher compression ratios.
- When enhanced JPEG is applied, a compression of 30-70:1 can be achieved without much visible degradation of image diagnostic quality. This can give an improvement by a factor of 3-7 in reducing image transfer time.
- Variable amount of compression can be applied to certain types of images without making much of visual difference. By applying variable compression, the loss of some of the pixels would not affect the perceived quality of the image. In such a case, it also does not significantly affect the radiologist’s interpretive performance.

- Image compression may be lossy (irreversible) or lossless(reversible) each one having some advantages, lossy compression gives higher degrees of compression whereas lossless compression allows the recovery of original image.

Stages of compression in radiological images are:

- Image transformation, in order to eliminate redundant information, reduce the dynamic range and, obtain a representation that can be coded more efficiently.
- Quantisation, by representing transform coefficients with the minimum precision necessary to achieve the desired image quality. The type and degree of quantisation has a great impact on the quality of the final image.

- Entropy encoding, a lossless compression process based on the non-random statistical characteristics of the transform coefficients.

  Consists of conversion of:

  1.cofficients into a sequence of symbols by a statistical method, followed by

  2. the symbols into data stream.

  The most commonly used encoding schemes for medical image compression are Huffman coding and run-length encoding(RLE).

  Huffman coding, assign short code words to the most probable messages and the longer code words to the least likely images.

- The digital picture is regarded as sequence of source messages that can be alternatively gray level of individual elements/ pairs of neighboring pixels/ arrays of elements of the original array.
- Run-length encoding uses pixel correlation. A run is defined in the digital image as a sequence of consecutive pixels of identical values along one direction. The efficiency increases when the no. of gray level transitions (edges) is low.
- Lossless coding methods exploit mathematical techniques that do not cause any information loss. They achieve maximum compression ratios in the range between 1.5:1 and 3:1. However, for a substantial practical and economic impact compression ratios closer to 10:1 or 20:1 are required.

The following are the various lossless techniques:

DPCM – Differential pulse code modulation

HINT – Hierarchical interpolation

DP – Difference Pyramid

BPE – Bit-plane encoding

MAR – Multiplicative autoregression.

- Lossy image compression techniques allow much higher compression ratios.
- JPEG (Joint Photographic Experts Group) is the mostly widely used. The recent extensions has improved performance. It is based on linear discrete transform of the type of DCT techniques.

- The wavelet transform, used for compression (30:1) of high resolution images such as mammography. It is also based on linear discrete transform with sub-band coding techniques.
- The other methods under study are : methods based on linear transforms are 2-D discrete cosine transform (DCT), full frame DCT, lapped orthogonal transform (LOT), sub-band coding.
- Other techniques include vector quantization, quadtrees, and adaptive predictive coding.

Transmission (modem) speed :

- A modem is the interface unit between the image digitiser and the transmission network.
- It is the data rate transfer speed of the modem which determines the transmission speed of transfer of the image.
- The speed of the modem is expressed in bits per second (bps) or baud rate.
- A sending station should be selected that it has reasonably fast modem with data rates 19,200 bps and above.
- A flexible arrangement will enable both the sender and the receiver to select the parameters which are more important on a case-by-case basis.

(2).A transmission network

- There are several communication modalities available for data transfer from one telemedicine station to another. Their choice would depend upon transfer rate requirements and economic considerations.
- The most commonly used transmission networks currently in use for teleradiology are those provided by the Internet service providers.
- Internet compatibility is increasingly a feature of modern teleradiology systems, enabling platform-independent transmission of images anywhere in the world.
- Image transmission time is directly proportional to the file size of the digital image. The file size would depend upon the size of the image pixel matrix and the number of bits per pixel.

- The quality of teleradiology has considerably benefitted from the recent developments in direct digital image capture methods, advances in transmission technology and improvements in telecommunication infrastructure.
- Using sophisticated image compression techniques, an X-ray can be compressed by a factor of 30. Using this kind of compression, low bit rate communication networks such as the cellular radio or mobile phones can also be adopted.
- The recent developments and research tools has seen increasing use of wireless technology. The most popular form wireless network referred to as wireless local area network, which conforms to IEEE 802.2.11 Wi-Fi standard.

- Web-based teleradiology has become popular because of its main advantage that dedicated image display software is not required to be installed on reviewer's computer. Instead the images are displayed inside a standard web browser.
- Web-based teleradiology is mostly used by dedicated teleradiology service providers, who are not affiliated to any particular medical facility but provide radiological reporting services for several institutions.

A receiving/image review station

A receiving station usually consists of:

(i) Network interface which is a modem

(ii) Personal computer with hard disk drive as storage medium

(iii) One or two display monitors

(iv)Hard copy printer

- The electrical pulses received at the receiving station from the network are converted back to digital image data by the modem.
- This data is then sent to the computer where it is stored in the disc.
- The radiologist can then access the image on the computer and uses image processing software to enhance the image features.
- Hard copy images can be obtained either on a multi-format camera or a laser printer connected to the receiving station.
- Performance requirements for a teleradiology receiving station are related to the specifications of the modem, computer hardware with image processing software, hard disc storage capacity, image archiving and retreival facility and TV monitor.

Modem: To ensure maximum transmission speed, the speed of modem at the receiving station should be equal to or greater than maximum speed of the modem at the sending station.

Computer hardware: The minimum requirements of a teleradiology system are:

- At least 4MB RAM with expansion capabilities
- High capacity hard disc drive
- High end Pentium processor based PC.

Image enhancement software: It is the essential component of a teleradiology system. Besides gray scale window/level and magnification controls of the image, other important software enhancement features that are normally included are colour, gray scale mapping, positive-negative reversal, edge enhancement, image flip/rotate and histogram capability.

Display monitors

- The most common requirements for display monitors at the receiving station are monitor resolution and screen size, recommended monitor resolution is usually above is 1024 x 1024. Generally recommended monitor size is minimum 32 inches.
- Split screen capability which facilitates the display of two or more different images on the same monitor screen at the same time, is a desirable feature in a teleradiology display station.
- Monitor brightness expressed in foot-lambert, is another important parameter relating to the maximum intensity of white light that the monitor can display. This information is relevant when teleradiology viewing stations are compared for their contrast quality.

- All equipment should comply with the DICOM standard.

Archiving and retrieval

- Teleradiology systems should provide storage capacity sufficient to comply with all relevant regulations regarding medical record retention and retrieval.
- Images stored at either sites should meet the jurisdictional requirements of the transmitting site.
- Each facility should have policies and procedures for archiving and storage of digital image data equivalent to the policies of protection of hard copy storage media to preserve imaging records.

Types of Teleradiology Systems

In practice, there are three types of teleradiology systems:

(i) On-call: Typical "on-call" teleradiology systems are most frequently used for after-hour, "on-call" applications.

(ii) Off-site: "Off-site" systems are set up mostly by radiology specialists and hospitals to establish central database with a view to expand interpretation network.

(iii) In-hospital: In-hospital systems are meant to be used to transfer images within the same facility over a LAN.

TELEPATHOLOGY

- Pathology is the medical specialty concerned with the study of the nature and causes of diseases in tissues and organs by examining cell and issue sections using a microscope.
- In telepathology the diagnosis is made remotely by studying the transferred microscopic images of tissue samples.
- The main recognised applications of telepathology include the usual telemedicine applications, namely telediagnosis, distant learning and teaching, remote image and data processing and quality control.

Telepathology Applications

Telepathology applications can be divided according to the management and the interactivity of images into:

- STATIC TELEPATHOLOGY(Teleconsultation): Done with Static Images sent for consultation in various ways(ftp, www, static images under video telephony, modem, etc..).
- KINETIC TELEPATHOLOGY: Includes the capacity to monitor the microscope at distance in order to do the sampling. Images are sent in full resolution either as static images, as highly compress images (i.e. through Videoconferencing standards) or both at the same times (i.e. for intraoperative specimens).
- DYNAMIC TELEPATHOLOGY: includes the previous option with the capacity of having full colour non-compress images at a real time(Live) .

Specific requirements for a Telepathology delivery system

1. Multimedia data-base to review previous biopsies (query, clinical history)
2. Colour Images of sufficient resolution (microscopic power dependent)
3. Interactive control and knowledge colour spectrum response camera/display.
4. Controlled sampling
5. Security and confidentiality tools

Multimedia database

- Is a preliminary condition, since no diagnosis can be done without patient's clinical history and knowledge of previous biopsies.
- When previous biopsies are archived in the referral laboratory, they should be available (in the database) for comparison purposes.
- An efficient method of query or selection per patient and type of diagnosis is important.

Colour images of sufficient resolution

1.Dynamic range

The dynamic range of a system is defined as the difference between the saturation level and minimum detection level detected by the capability of the detection change.

$$Dr = S_{max} - S_{min} / S_{dif}$$

S_{max} = Saturation level or maximum value to be detected without saturation.

S_{min} = Detection level or the minimum value capable to be detected.

S_{dif} = minimum magnitude change to be able to detect by the system.

- Diagnosis in pathology is based on colour images, that is with 8 bits of dynamic range may produce sufficient information; the reason being that the pathology acquisition systems are based on Video cameras that have an implicit non-linear response (gamma correction).
- This effect on the image is inverted by gamma correction of the display systems obtaining a final effect of an adequate visual perception.

2.Spatial resolution

In the digital sampling of pathology images the spatial resolution is of a paramount importance in the accurate visual perception, and therefore:

a) Introduces variability on the minimum requirements for a capture system depending on the microscopic power used.

b) Is directly related to the capacity of pathology images to support lossy compression algorithms.

If minimum requirements on spatial resolution is required, compression maybe possible without sensible loss of visual information.

Sampling theory

- Spatial frequency is related with the amount of information present in one spatial dimension unit.
- Spatial resolution is defined as the maximum spatial frequency (F_{max}) able to be detected or transmitted; for digital images, it represents the two-dimensional pixel matrix of the acquisition device.
- Sampling theory tries to reduce to a reasonable limit the amount of information that should be stored and processed to avoid heavy computation processes and optimise transmission over the network.
- According to the **Sampling theory of Shannon** (sample frequency or distance), in order to assure that a discrete sample (digital) will unequivocally reproduce an analogue (continuous) image, samples should be taken at 2Fmax. It means that double of the maximum spatial frequency; all this limited by the signal to noise ratio of the system.

Shannon theorem:

$R<2*B$

$n=\sqrt{1+ \text{signal/noise}}$ (n=sqrt(1+ signal/noise))

$D=R*\log_2(n)$

$D<B*\log_2(1+ \text{signal/noise})$

- That is the reason why 512x512 image sampling can provide good quality images but that could be unacceptable for lower power sampling, where the amount of information per space unit is much higher.
- The high resolution cameras available in the market (still too expensive) directly record digital images with very high spatial resolution. Two main consequences are derived from this technique:
  - A recorded image at a low microscopic power can support digital zooming simulating higher power microscopic views.
  - The image is not affected by the gamma correction of the Video-systems depending on the cameras- and is therefore comparable to a digital radiography from the visual perception and image processing point of view.

3.Compression methods

Address the issue of how to reduce the amount of data without a sensible loss of important information. The term “important” varies according to the subsequent analysis procedures:

a) Visual inspection or diagnosis

b) Image analysis

c) Image quantitation

Include techniques of luminance and colour reduction (reduction of dynamic range), spatial resolution reduction, or both, as well as simple data reduction.

A. Colour reduction techniques:

A.1. Through YUV coding. Usually based on colour sampling reduction of 8/4/4 bit information acquisition.

A.2. Reduction of colour palette to 256 colours (8 bits).

A.3. Median cut colour quantisation. It is a colour quantisation technique that optimises the representation of the original colour in the final palette.

- This technique produces median cuts of colours on RGB to reach 256 colours, therefore the most frequent colours have greater range of colour gradation than infrequent colours.
- This can be further optimise by dithering that appears to expand the available colour palette by juxtaposing pixels of different colours to create the illusion of additional colours by visual blending.
- In diffusion dithering this is accomplished by calculating the numeric difference between the original and final colour of each pixel and distributing this difference among the neighboring pixels.

B. Spatial resolution reduction : Includes sampling reduction with or without inter-pixel interpolation i.e. digitize one in every two pixels.

C. Data reduction : Includes the classical lossy or lossless compression methods.

Interactive control of colour

- Misinterpretation of colour at the receiving point is n important cause of error together with sampling problems.
- Therefore , a minimum knowledge of the colour theory is required to understand the need for interactivity due to various Spectral Responses as well as built in Gamma Correction that cameras and displays provide, and that affects the colours and visual perception.

Controlled sampling

- Diagnostic discrepancies due to sampling error are in the range of 9 to 6.3 percent.