15

Image management and communications technology

GARY F. EGAN

The history of medical imaging can be dated from Rontgen’s discovery and first clinical use of X-rays in 1895. These first X-ray images were humble portents of the increasingly important role which medical imaging has assumed, particularly in the last 25 years. In fact, diagnostic radiology continued more or less unchanged from Rontgen’s discovery until digital computers were integrated with electronic imaging technology in the 1970’s. After Hounsfield (Hounsfield 1973) and Cormack’s development of computerised tomography (CT) there was been a rapid proliferation of new medical imaging technologies. These new technologies are now playing an increasingly important role in clinical diagnosis and patient management. With improvements in computing and communications technology continuing unabated, increased clinical utilisation of digital imaging technologies seems assured.

Major medical imaging technologies

Diagnostic imaging non-invasively probes the interior of the human body to reveal an intrinsic attribute such as the structure or functional condition of the tissue. The practice of radiology is based on the exquisite sensitivity of X-rays to variations in the density of different bodily tissues, eg. bone and muscle. The variable attenuation of X-rays by different bodily tissues enables an image of structure or anatomy of the body to be generated (Table 15.1). Planar X-ray films provide projection images of the line integrals of the X-ray beam attenuation coefficients through an object. By using a computer controlled rotating X-ray tube and detector system many projection images from different views through the object can be acquired. By applying a mathematical transformation, known as the inverse Radon transform, to these X-ray projection images, tomographic *(tomo-slice, Greek)* images or transaxial views through the body can then be produced. The invention of computerised tomography (CT) revolutionised radiological practice and provided unparalleled images of the interior of the body. Whilst both X-ray and CT provide anatomical images, nuclear medicine techniques based on the in-vivo administration of tracer amounts of radioactivity provide complimentary images of bodily function.

Table 15.1 The most common non-invasive diagnostic imaging technologies categorised by probe type and distinguishing attributes

Modality	Quantity probed	Probe	Attributes
US	velocity[1]	sound	anatomical, functional, dynamic
X-ray	density	X-ray	anatomy, simple, static, high resolution
CT	density	X-ray	tomography, anatomical
MRI	proton	RF[2]	tomography, anatomical, some function
NM	-	γ-ray	simple, planar, function
SPECT	-	γ-ray	tomography, function, qualitative
PET	K[3]	β+	tomography, function, quantitative

[1] The velocity of sound is dependent on the adiabatic bulk modulus coefficient of the tissue

[2] RF denotes the radio frequency of the alternating magnetic field

[3] K denotes the metabolic rate constants of organ or tissue function

Nuclear medicine (NM) evolved during the post World War 2 period as probably the most universally condoned peaceful use of nuclear technology. Nuclear medicine is based on imaging the in-vivo bio-distribution of an administered radioisotope labelled pharmaceutical, which provides an image of the functional capability of bodily organs or processes. The application of Hounsfield’s work to planar NM images resulted in tomographic functional images, or single photon emission computed tomography (SPECT) images. More recently another radioisotope tracer technique positron emission tomography (PET), has provided quantitative non-invasive images of bodily function such as metabolism and blood flow.

Magnetic resonance imaging (MRI) probes the body through the use of high frequency magnetic fields which are tuned to be sensitive to the distribution of free protons within the body. Free or semi-free protons are most commonly found in water, and thus MRI is maximally sensitive to soft bodily tissues and to small variations between different soft tissues. Consequently, MRI images resolve finer anatomical detail, particularly in the brain and spinal column than CT images. More recently, MRI has been developed to image cerebral angiography (MRA) and functional imaging such as cerebral blood flow now appears to also be possible with MRI (Prichard JW & Rosen BR 1994).

Medical imaging technologies can be categorised according to their temporal resolution, with all of the above techniques essentially providing static images. In contrast, dynamic images are provided by ultrasound (US) where a continuously transmitting and receiving probe (transceiver) provides continuously varying anatomical images. Dynamic anatomical imaging using visible light is also performed using endoscopic techniques but as these techniques use invasive video based technology, they are generally considered separately from non-invasive techniques imaging and will not be discussed further. With the advent of digital ultrasound systems three dimensional (3D) image visualisation as used in CT, MRI, SPECT and PET is now being developed for use in ultrasound.

The operation and management of medical imaging systems in large hospitals has traditionally been confined to radiology and nuclear medicine departments. In smaller private practices these departments are frequently combined. Digital integration of these systems using computer networks has until the last few years been fraught with difficulties due to the absence of networking standards for medical images. DICOM 3.0 is the most commonly accepted digital image communication standard (ACR/NEMA 1988) in medicine and now enables standardised exchange of digital images between imaging systems and other networked devices, including large data archives. Together with technological advances, standardisation makes possible the actual implementation of picture archive and communication systems (PACS), sometimes known as image management and communication systems (IMAC). With the major technological barriers to PACS now overcome, determination of the impact and cost effectiveness of these systems on patient care is now possible. PACS implementations are presently underway at a number of institutions including the United States Army, Madigan (MDIS project) and at the Hammersmith Hospital, London. Recently two Australian hospitals namely St. Vincent's Hospital, Melbourne and the Royal Children's Hospital, Sydney have embarked on staged implementation of PACS systems. Following difficulties with an earlier PACS project at the John Hunter Hospital, Newcastle the outcome of these two new projects will be pivotal to further expansion of PACS in Australia.

Image management and communication requirements

Television and cinema have proven that the production and distribution of images is extraordinarily important and influential. Generally new developments in imaging technology are rapidly incorporated into medical imaging systems, but the same has not been true for image distribution and display technologies. Surprisingly, digital medical images are routinely filmed for subsequent hard copy viewing by radiologists and nuclear medicine physicians. Films are also manually distributed to other internal or external hospital departments, and are used for permanent storage. Whilst electronic transmission, display and storage of images are possible most digital medical imaging systems produce film to perform these functions.

Digital image management and communication has not yet overtaken film because rapid clinical access to images requires communication bandwidth in excess of 100MHz, a very high degree of reliability of image availability, massive and rapid data storage capacity, readily accessible image viewing workstations, and most importantly significant changes in work practices throughout a health care institution. Technological solutions to most of these problems have now been developed but the cost-effectiveness of an integrated system in a clinical setting is yet to be established. Rapid communication of images for clinical viewing remotely from an imaging department can be achieved using optic fibre technology operating at speeds of 100 MHz (100 Mbps). Actual data transfer rates of 30 Mbps (Rowberg & Zick, 1992) result in image transfer times of three seconds or less for single patient studies (Table 15.2). The development of higher speed technology and a new communication standard called asynchronous transfer mode (ATM) will permit communications up to at least 600 MHz within the next few years. The communications requirements for PACS will then have been substantially exceeded.

Table 15.2 Typical image sizes, communication transfer periods and annual data storage requirements for a medium sized (500 bed) hospital

Modality	Data/image (MB)	Images/ study	Data/study (MB)	Transfer time (sec)	Studies/ day	Data/yr (GB)
X-ray	6	1-3	12	3	15	36
CT	0.15	30-60	7	2	20	28
MRI	0.15	60-120	13	3	20	52
US	0.1	20-30	2.5	1	10	5.0
SPECT	0.03	15-30	0.6	0.15	6	0.7
PET	0.03	30-60	1.3	0.3	4	1.0

The reliability of images via a PACS depends on the reliability of each component of the system. The central image database, which may consist of a number of server computers, must be continuously operational and accessible. Redundant arrays of inexpensive disks (RAID) permit data recovery in the event of a single disk failure. By stripping data across many disks, RAID disk technology allows for re-assembly of data in the event of a single disk failure. Consequently with rapid disk maintenance, data integrity can be assured to a very high level of confidence. RAID disk technology effectively assures the medico-legal requirement in various parts of Australia of maintaining diagnostic imaging results for five years or more.

Computer network reliability has improved dramatically over the past few years, particularly for Unix systems using the tcp/ip communications protocol. The security of data transmissions using tcp/ip has also dramatically improved, which is crucially important for non-isolated networks. The lower cost of diagnostic quality image viewing workstations permits banks of six or more monitors for comparative image viewing at reasonable cost. However monitor specifications are being tightened considerably to ensure that image interpretation is reliable and independent of monitor performance and characteristics. Multi-terabyte (1 TB = 1000 GB) optical disk storage units are also now available, albeit at significant expense. Finally, the significant benefits of a PACS system can only be realised when staff work practices fully incorporate the new technologies. Changes to work flow, staff skills, and actual staff numbers are necessary, as well as a financial commitment to continual system maintenance and development.

Medical IMAC systems

The earliest medical image management and communication systems date from the mid 1980’s when the US. Army funded PACS system development at the Washington University, Seattle and the Georgetown University, Washington DC. These systems have been progressively updated and are still in operation today. More recently there have been four major PACS projects installed and initial operational experiences with these systems have been reported (Irie 1991, Masser et al 1991, Glass & Stark 1991, Goeringer 1991).

The US. Army has funded the successful medical diagnostic imaging support (MDIS) system at four army hospitals, of which Madigan, Washington is the most well known. The MDIS technical specification is extremely comprehensive and has been used to specify requirements at a number of other PACS projects (Goeringer 1991). Probably the largest PACS project is at Hokkaido University Hospital, Japan in which the PACS, hospital information system (HIS) and medical records are integrated (Irie 1991). Typical characteristics of the system are on-line image availability for one week, with image retrieval times of 40-60 seconds from optical disk library; twenty 1024 by 1024 pixel monitors for radiological image reporting; inclusion of echocardiography, endography, and microscopy images; and 200 terminals providing sub-diagnostic image quality access to the system. The clinical evaluation has concluded that from a users point of view the system is too slow, that the image quality is generally as good as film, and that workstations with more than two monitors are required.

The decision to implement a PACS system at the Hammersmith Hospital, London has been substantially based on their cost-benefit analysis (Glass & Slark 1991). The cost benefit analysis included both direct components such as film, labour, and space utilisation, and indirect components such as improved productivity due to improved efficiencies, reduction of hospital in-patient stay, and reductions in repeated procedures. The system specification is based on the MDIS specification. Finally, the Vienna Hospital PACS project also incorporates the HIS and radiology information system (RIS) and has been developed jointly by Siemens and the hospital (Masser et al 1991). The communications architecture is a token ring topology using 100 MHz fibre digital data interchange (FDDI) protocol. Image display within radiology is based on high resolution (1024 x 1280 pixels) monitors, whilst elsewhere in the hospital PC based systems are used.

A number of other notable PACS systems have been developed including the Geneva DIOGENE system which integrated the PACS within the previously (in-house) developed HIS (Ratib 1992). All of the PACS systems described have multi-million dollar implementation budgets, and can generally be considered to be second generation systems. Third generation PACS systems building on the successes of the second generation systems are now in planning. Such systems benefit significantly from the recent rapid advances in PACS component technology (networks, storage, monitor) and may actually be cost-effective in their implementation.

Australia’s first PACS project was initiated with the construction in the mid 1980’s of a new hospital in Newcastle, the John Hunter Hospital (Crowe, 1990). Whilst state-of-the-art technology such as optic fibre for communications was installed in the hospital, the project was hampered by the absence of image data and high speed communication standards, the high cost at that time of the necessary technology, and most importantly the lack of functional applications and quality user interfaces. The project was partly promoted as a cost effective means of utilising building and staff resources, but even today with greatly decreased technology costs full PACS implementations are probably only just becoming cost effective. The failure of the John Hunter Hospital PACS project has undoubtedly retarded development of PACS elsewhere in Australia. Recently, an expanded project including telemedicine services between four hospitals in the region has been proposed (Osborne 1994). This project has greater emphasis on telemedicine services between Australia and South East Asian hospitals, anticipating a new revenue stream for these services to improve the cost benefit analysis of computer and communications investment in each individual hospital.

St Vincent’s Hospital, Melbourne is planned to be filmless after relocation to new buildings presently under construction. The PACS system is planned to be implemented in four stages from mid 1994. Stage one involving installation of a computed radiography (CR) or digital X-ray system with image distribution from the Department of Radiology to ICU has already been completed. Stage two (expected in mid 1995) involves filmless operations within the Division of Medical Imaging. Data archive and intra-division image communication are required for the existing MRI, CT, SPECT, Ultrasound, DSA and CR systems, with up to three additional CR systems expected within two years. Stage three is completion of the PACS system and is planned for early 1996, with filmless operations being extended throughout the whole hospital at that point. Finally stage four involves interconnection of the PACS with the RIS, but specific details of this stage are dependent on details of the PACS system chosen. The hospital is committed to a major investment in PACS and the project outcome will undoubtedly influence the development of PACS elsewhere in Australia.

Relocation of the Royal Children's Hospital (RCH), Sydney to a new site adjacent to Westmead Hospital in western Sydney has been the impetus for the installation of a partial PACS in that hospital. Telemedicine requirements play a major role in the design of the RCH PACS, with paediatric image transmission from rural and remote areas to the RCH an existing service (Crowe 1993). Expert paediatric radiological opinion is in many cases crucial to patient management prior to transfer to the RCH. CT and X-ray images are presently transmitted from hospitals in central and western New South Wales using ISDN and Fastpac communication links. Stage one of the RCH PACS implementation specifies distribution of CR images to ICU, with film continued to be used both within the Division of Medical Imaging and the rest of the hospital. Later stages of the PACS implementation identify filmless operation with the Medical Imaging Division and then throughout the hospital.

Finally, the installation of state-of-the-art PET and MRI scanners has been the impetus for PACS related developments at the Austin Hospital, Melbourne. The Austin Hospital is a tertiary referral hospital with particular clinical strengths in the areas of neurology (epilepsy and spinal injuries), neurosciences, liver transplantation and cardiac surgery. A campus wide ethernet computer network was installed in early 1992, with internet access via an ISDN link to the University of Melbourne. More recently microwave links to other hospitals in the region have been commissioned. The network is presently utilised for image communication, email distribution, electronic information access, library CD-ROM catalogue searching, a list server for hospital staff communications. Access to the HIS has been demonstrated. Presently there are over 100 computers and over 250 users on the network (Egan 1993a).

The initial PACS development at the hospital is a networked medical image database project (Egan 1993b). This project which is aimed at centralising neurosurgery patient image data from MRI, CT, PET and SPECT scanners is soon to commence clinical trialing at the hospital. The image database will provide co-registered images for multi-modality image viewing at neurosurgery patient contact locations within the hospital, as well as in the Division of Medical Imaging. Integration of the separate medical imaging (MINet) and the hospital information (HISNet) networks is a key infrastructure component for any successful IMAC. The major concern at the Austin Hospital in interconnection of the two networks has been the protection of patient confidentiality and the prevention of unauthorised access to patient related information.

Advances in medical imaging technologies

Medical imaging technologies have evolved particularly rapidly over the past two decades. The 1970's and early 1980's witnessed the invention of CT, SPECT, PET and MRI. Since then the major advances have resulted from increasingly powerful computers and specialist visualisation software. It seems likely that future advances will follow this trend with computer based techniques providing more and more diagnostic information from existing imaging technologies.

Comparing or overlaying images from different imaging systems has until recently not been directly possible. Firstly, different tissue characteristics are generally displayed in different image styles. For example, whilst CT images of the torso show the chest wall and skin surface, PET images of the same region preferentially show the functioning organs such as heart and liver. Secondly, different orientations, magnifications, and distortions can exist in each different image type. And thirdly a common image format (DICOM 3.0) is only now becoming more widely accepted.

There have been two principle types of over-laying or coregistering medical images developed, the landmark technique (Evans et al 1991) and the surface matching technique (Pelazarri et al 1989). Both techniques determine a linear transformation of seven degrees of freedom (three translations, three rotations, and one magnification) between the two image types. Either image can then be transformed into reference space of the other image for direct comparison. Coregistered image sets are being increasingly demanded by surgeons to enable them to unambiguously resect only those tissues implicated in a clinical problem. For example, thoracic surgeons at the Austin Hospital now require coregistered CT and PET scans for lung cancer patients, so that only the metastatic nodes involved in the disease are identified and removed during surgery.

Coregistered image sets can also form the basis for computerised neurosurgery planning in which procedures can be practised by manipulating image sets prior to the actual surgery. A recent innovation is the neurosurgical computer wand or probe, in which the probe's movement in space is monitored by a computer (Peters et al 1993). The probe is initially oriented to the patient's scalp by simultaneously touching scalp points and controlling a computer joystick to identify the same points on the patient's images. Subsequently if the neurosurgeon uses the probe to point to a region within the patient's brain the computer image can show the exact probe location in cut away views. This can significantly enhance the neurosurgeon's spatial localisation for tissue resection or biopsy.

The conventional means of displaying an image is as a set of parallel slices, generally a set of transaxial slices perpendicular to the long axis of the body. Views form any direction can then be calculated and displayed as either a surface rendered object or as a volume rendered object. A surface rendered image is produced by determining along each line of sight through an object the first image voxel which has an intensity greater than a chosen threshold (fig 1). Whilst surface rendered images greatly assist in applications such as craniofacial surgery where the external appearance is crucial, most other medical visualisation applications actually require volume rendered images. Volume rendered images are constructed by applying an opacity weighting function along each line of sight through an object. The intensity of each pixel in the resulting image is the summation of the product of the weighting function and intensity of each voxel along the entire line of sight. The weighting function can be adjusted to give greater weight to deep structures, enabling visualisation of internal structures whilst still retaining an overall perspective of the object (fig 2).

Automated image segmentation and tissue classification tools have been developed by a number of groups (Collins DL et al 1992, Kamber et al 1992). One technique uses computers to utilise the greater 16 bit dynamic range of digital images. The human eye is sensitive to 12 bit images at best, and generally to lower dynamic ranges. An algorithm to segment an anatomical image into regions having different characteristic intensities was an early attempt to classify tissue types present in an image, since similar tissue types could be expected to have similar intensities. More recently machine vision techniques which use image segmentation algorithms together with knowledge based databases offer the possibility of automatically identifying normal and abnormal regions within an image. These tools can be used to enhance diagnosis and reporting of disgnostic images as well as providing objective analysis tools for medical research based on non-invasive imaging techniques.

References

ACR/NEMA Publication 300-1988 (1988) Digital imaging and communication, American College of Radiology/National Electrical Manufacturers Association, Washington DC.

Collins DL, Peters TM, Evans AC (1992) Multiresolution image registration and brain structure segmentation. Proceedings IEEE EMBS 14th annual international conference, France pp 105-109

Crowe B (1990) International developments in PACS. Australian Institute of Health and Welfare, Canberra

Crowe B (1993) Telemedicine in Australia. Australian Institute of Health and Welfare, Canberra

Egan GF, O’Keefe GJ, O’Callaghan D (1993a) Computer networking and network applications at the Austin Hospital, Melbourne. In: Hovenga E (ed) Proceeding of the inaugural health informatics conference, HIC ‘93, Brisbane

Egan GF, O’Callaghan D, O’Keefe GJ (1993b) Networked medical image database at the Austin Hospital, Melbourne. In: Hovenga E (ed) Proceeding of the inaugural health informatics conference, HIC ‘93, Brisbane

Evans Ac, Marrett S, Torrescorzo J, Ku S, Collins L (1991) MRI-PET correlation in three dimensions using a volume-of-interest (VOI) atlas. Journal of Cerebral Blood and Metabolism 11:A69-A78

Glass HI, Stark NA (1991) PACS and related research in the UK. In: Huang HK, Ratib O, Bakker AR, Witte G (eds) Picture archiving and communication systems in medicine, NATO ASI series F74, Springer, Berlin.

Goeringer F (1991) Medical diagnostic imaging support systems for military medicine. In: Huang HK, Ratib O, Bakker AR, Witte G (eds) Picture archiving and communication systems in medicine, NATO ASI series F74, Springer, Berlin

Hounsfield GN (1973) Computerised transverse axial scanning (tomography). Part 1 : Description of system. British Journal of Radiology 46:1016-1022

Irie G (1991) Clinical experience - 16 months of Hu-PACS. In: Hong H K, Ratib O, Bakker A R, Witte G (eds) Picture archiving and communication systems in medicine, NATO ASI series F74, Springer, Berlin.

Kamber M, Collins DL, Shingal R, Francis GS, Evans AC (1992) Model based 2D segmentation of multiple sclerosis lesions in dual echo MRI data. SPIE Visualisation in Biomedical Computing 1808

Masser H, Mandl A, Urban M, Hradil H, Hruby W (1991). The Vienna project SZMO. In: Huang H K, Ratib O, Bakker AR, Witte G (eds) Picture archiving and communication systems in medicine, NATO ASI series F74, Springer, Berlin.

O’Keefe GJ (1994) Personal communication

Osborne P (1994) Personal communication

Pelazarri CA, Chen GTY, Spelbring DR, Weichselbaum RR, Chen C (1989) Accurate three dimensional registration of CT, PET, and/or MR images of the brain. Journal of Computer Assisted Tomography 13:22-26

Peters TM, Davey B, Comeau R, Henri CJ, Munger P, Charland P, Evans A, Olivier A (1993) Online stereoscopic image guidance for neurosurgery. Nuclear Science Symposium and Medical Imaging Conference III:1805-1809, IEEE, New Jersey

Prichard JW, Rosen BR (1994) Functional study of the brain by NMR. Journal of Cerebral Blood Flow and Metabolism 14(3):365-372

Ratib O (1992) Evolution of PACS concepts. In: DeValk JP (ed) Integrated diagnostic imaging, Elsevier, Amsterdam.

Rowberg AH, GL 1992 PACS - clinical evaluation and future conceptual design. In: De Valk J P (ed) Integrated diagnostic imaging, Elsevier, Amsterdam