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Telemedicine

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This chapter examines; the potential impact of telemedicine on remote health care practice; requirements for transmitting medical data over networks; communication bandwidth limitations and their impact on data transmission; digital imaging and the compromises of image compression and problems of evaluation and cost-benefit analysis

Health care and telecommunication

Telemedicine can broadly be defined as health care services delivered through telecommunications networks. The concept of using telecommunication for patient care is probably as old as the telephone. Telemedicine, however, is more than simple voice communication over telephone lines, it includes the transmission of still images, video, and other forms of medical data.

Some of the earliest experiments using video and sound communication for health care were carried out in the space missions of the 1960's, by the United States and Soviet Space Programs. Today telemedicine is predominantly seen as a way of delivering tertiary health care to rural centers that have limited health services, with the objective to provide equal health care services regardless of geographical location.

Telemedicine is undergoing a surge in popularity in many countries, with considerable interest and investment from the computer and communications industries. Most states in Australia now have some pilot or established telemedicine project linking major hospitals to rural centers. Several factors have been responsible for the recent interest in the field—the most important is the rapid fall of the cost of hardware required to build a telemedicine system, including the cost of connecting remote sites.

The reality of geographic and socio-economic barriers to health care access in rural communities has been recognised for many years. Despite of this awareness, rising health care costs force many local hospitals to close, reducing access further. Health care workers in rural areas face professional isolation, and must deal with additional expenses for transportation when sending patients for referral. These problems outside urban centers increase the cost of health care to the individual patient, and therefore the entire system. It is believed that telemedicine can improve the standard of health care by providing medical intervention in a more timely manner, instead of the current practice of sending rural patients to urban hospitals resulting in delayed interventions.

Almost all medical specialties can be practiced via telemedicine. The most studied applications concentrate on areas in which there is a shortage of experts in rural communities, and in which the presence of visual data prevent telephone consultations from being effective. Examples include radiology, histopathology, dermatology, ultrasonography, and other imaging studies. Mental health care has also been one of the early applications of telemedicine.

Transmission of medical data

Telemedicine is a collection of technologies including computers, communication networks, video, and specialised medical equipment. The most common feature of a telemedicine system is the ability to transmit high-quality medical images across a communication line. To understand how this is achieved it is important to understand the difference between digital and analog data.

Analog signals vary continuously. An example of an analog signal is an ECG which is recorded on a printout. Traditional sound and video data are also analog signals. Computers deal with digital data, so analog signals must be converted to digital signals that are stored in discrete units. The process is known as *analog-to-digital conversion* (ADC). An important advantage of digital signals is that they can be transmitted through a digital communication channel irrespective of the source of the signal, so digitised voice, video, ECGs, X-rays, and so on, may be sent through the same communication channel. In this section we will explore how various medical data can be digitised and transmitted.

Still images

When an image is digitised it is stored as a matrix of *pixels* (picture elements). Many computer screens can display at least 640 x 480 pixels. If each pixel is represented as a bit in the computer then it can be in one of two states, “on” or “off”, which may correspond to two colours, say black and white. Almost all medical images require colour or many levels of grey so each pixel must be represented by more than one bit in memory. If a pixel is represented by n bits in memory it is said to have a pixel *depth* of n, and the pixel can take on one of 2^n colours. An example is a computer screen that can display 256 colours, such a display will require a pixel depth of 8 bits per pixel. Because computer images have this third dimension they are often described in terms of width x height x depth.

The amount of memory required to store an image varies considerably depending on the source of the image. An digitised X-ray is usually around 2000 x 2000 x 12, that is 12 bits per pixel with an area of 2000 pixels squared. The storage for such an image is about 6 Megabytes (Mb). In contrast a single CT slice requires about 512 x 512 x 12, or about 400 kilobytes (kb). Colour images require greater bit depth, around 24 bits per pixel, to represent smooth colour transitions. Fortunately clinical images, or histopathology images can be around television resolution for most purposes, say 800 x 600 x 24, requiring almost 1.5 Mb per image.

Video

Video images of the patient are often required for adequate patient assessment. In the simplest terms video can be thought of as transmitting still images 25 to 30 times per second to give the illusion of movement. The human eye is less perceptive to detail in moving images so video images tend to be around 300 x 200 pixels in size with a pixel depth of 16 bits for colour, or 8 bits for grey scale. Although 25 to 30 images, or frames, per second is the speed at which the television standard works (broadcast quality), lower rates of around 15 frames per second are adequate for many purposes not involving rapid movement. Frame rates below 10-15 are noticeably jumpy and can be irritating to view.

The data rate for raw video information is enormous. Consider that a 300 x 200 x 16 still image requires about 120 Kb, but at a video rate of 15 frames per second the data transmission rate required is 1.8 Mb per second! Obviously transmitting raw video signal is not efficient, compression techniques for still images and video will be discussed later in this chapter.

Telemedicine technologies

Telecommunication

Telemedicine is primarily concerned with the transmission of medical data between rural and urban areas, so it is important the technology takes advantage of existing communication infrastructure to be cost-effective. Copper telephone wire is the most common form of communication channel connecting distant centers. Unfortunately telephone wires were not designed for fast digital communication and there is a limit to how fast data can travel through this medium. The capacity for information transmission of a communication medium is called *bandwidth*.

Modems (modulator-demodulators) are a common computer peripheral used for digital communication between two points using telephone lines. Modems convert digital signals into analog sound waves and transmit these analog signals to a receiving modem over a standard telephone connection. The receiving modem then converts the analog signals back into digital signals. The problem with this technique is that standard telephone connections are *noisy*—there is interference which limits the maximum bandwidth, especially to rural areas. Low-cost modems are available with speeds of 14.4 kilobits per second (kbps). Faster modems are now becoming available but it is not clear that speeds higher than 14.4 kbs are reliable over long distances due to line noise.

The unique conditions in Australia—a small population and large distances—have motivated some telemedicine projects to use satellite connections between tertiary centers and very remote regions (Watson 1989).

Integrated Services Digital Networks (ISDN)

ISDN improves the potential bandwidth of communication by transmitting data digitally from one point to another, for the most part, using existing telephone switches and wiring. Although the cost of ISDN has prevented its widespread use amongst home computer users (compared to modems) this technology is the most commonly used medium for telemedicine. The ISDN “basic rate” provides 56 or 64 kbps of data transmission, and two voice lines. ISDN lines may be aggregated to provide greater bandwidth, so two lines would allow 128 kbps communication.

To put the limitations of ISDN using copper telephone wire into perspective, most universities and many businesses use twisted pair or coaxial wire cabling for data transmission rates between computers of around 10-16 Megabits per second (Mbps). Fiber optic connections can provide speeds of over 150 Mbps. The speed of ISDN communication is a major constraint when designing equipment to be used in telemedicine applications.

Compression

In a remote telemedicine consultation the time for image transfer must be minimised—it is not acceptable for busy physicians to spend a significant amount of time simply waiting for image data to arrive. If the technology interferes with the flow of medical practice the resulting poor user satisfaction will prevent its widespread use. It is clear that raw visual data cannot be sent through ISDN lines in an interactive fashion. Data compression is used to reduce transmission times by reducing the storage size of image and video data.

There are two general types of image compression: lossy, and lossless. In general lossless compression methods can compress data about 2:1 on average. Lossless compression guarantees that the process of compressing and decompressing an image will not change the image in any way (all the pixels will have the same value before and after compression). Although halving the memory required to store and transmit the image is good, much better rates of compression can be achieved by using lossy compression.

Lossy compression

Lossy compression techniques achieve much higher rates of compression than lossless methods by discarding some of the information in the image. Although this sounds alarming at first, most lossy compression techniques take advantage of the fact that the human eye is perceives small colour changes less accurately than small changes in brightness. Therefore, by removing small differences in pixel colour much greater compression rates can be accomplished, usually in the range of 10:1 to 20:1 without much loss in image quality. The amount of compression, and therefore image degradation, can be selected by the user.

The most commonly used lossy compression technique is the Joint Photographic Expert Group (JPEG) image compression mechanism (Wallace 1991). The advantage of JPEG compression is that it is widely available on many computer platforms. JPEG compression has been used for teleradiology and for picture archive and retrieval systems (Kajiwara 1992). The standard JPEG compression technique compresses the whole image using the same compression factor, regardless of regions of interest that one might want to store in higher quality. Other methods of lossy compression exist but most are based on the same basic technique as the JPEG algorithm (the discrete cosine transform). Some variations of lossy compression have been customised for X-ray images—using lossy compression for areas of high contrast which will not be significantly affected by the information loss (Wilson 1992).

Video compression

Video is amenable to lossy compression because the eye does not have time to detect imperfections on a single frame. The largest gains for video compression derive from a technique known as *frame differencing*. Frame differencing calculates what parts of the image have changed between two frames and only transmits the differences instead of a whole frame.

The International Telegraph and Telephone Consultative Committee (CCITT) has recommended standards for transmitting compressed sound and video over ISDN connections

(CCITT 1990). The standards, grouped under the name H.320, provide for up to a 352 x 288 image at to 30 frames per second, although the frame rate will depend on how many ISDN lines are aggregated. This standard was designed for teleconferencing and not specifically for telemedicine.

Interpretation of compressed images

A lossy compression technique can potentially reduce an X-ray image from 6 Mb to 600 kb with on a small loss of quality. An uncompressed image would take 12.5 minutes to transmit using a 64 kbps ISDN connection (assuming 100% efficiency), but if compressed at 10:1 using lossy compression the time required to transmit is under 1.5 minutes. Why not compress all data if there is such a significant time saving? Why not compress images at higher compression rates? The answer is, of course, image degradation.

The effect of lossy compression on clinical diagnoses has been studied in a few areas. Compression rates around 10:1 (Cosman et al 1994) up to 20:1 (Aberle et al 1993) did not change the detection of abnormalities in thoracic X-rays and CT scans, or in hand X-rays (Sayre et al 1992). At least one study has shown that there is a significant decrease in diagnostic accuracy when interpreting on-screen X-ray images of subtle orthopedic fractures (Scott et al 1993). These conflicting results indicate that further research is required to see what classes of image are amenable to lossy compression without significant loss of diagnostic information.

There is some early evidence that lossy compression methods in telemedicine may not adversely affect diagnostic accuracy of images in remote consultation for ultrasonography (Beard et al 1993), histopathology (Weinstein et al 1992), dermatology (Perednia et al 1992), and other clinical disciplines.

Components of a telemedicine system

In the past most telemedicine systems were built specifically for a hospital and the remote site, usually at great expense. Today, there are numerous telemedicine hardware vendors providing “off-the-shelf” systems. Each system varies in the exact specifications, but the basic components of a telemedicine system are similar.

A telemedicine system requires remote connections, usually through ISDN. Video and audio are provided using a high-resolution video camera, and a video-tape recorder. The analog image from the video camera is digitised using ADC hardware, after which the resulting image is compressed. Image compression is done by a hardware component called a *codec* (compressor-decompressor). Most telemedicine vendors have their own proprietary codec which is optimised for their own computer and display systems. It is very important to make sure that the proprietary codecs also support industry standards like JPEG and H.320 so systems from different vendors can interoperate. The teleconferencing and image manipulation in telemedicine is controlled by a computer system.

There are numerous attachments that can be added to the telemedicine system to allow the remote physician to gather data about a patient. An electronic stethoscope is often provided to allow the heart sounds of a patient to be transmitted over the audio channel. Telepathology systems may include a facility for the consulting pathologist to control the movement of the stage and the zoom of a microscopy across the country, only relying on technicians to prepare and mount the slides. Direct control of remote equipment such as a microscope, endoscope, or other operative instruments requires even higher bandwidth communications and sophisticated user-interfaces because the control signal must appear to be synchronised with the visual feedback from the device (Keil-Slawik et al 1991).

If X-rays, ultrasound, ECGs, and other medical data are to be transmitted via a telemedicine system then specialised hardware is required to digitise the data, or transfer the data if it is already in digital form (for example, CT scans).

Usability and evaluation

Human factors

The technical problems of telemedicine are well recognised and solutions will improve as computers and networks become faster. It is not entirely clear how the use of telemedicine will impact the practice of medicine, or if in fact there are long-lasting cost and health related benefits to telemedicine consultations.

There are numerous changes to the way medicine is traditionally practiced when dealing with telemedicine consultations. The most obvious difference is that all patient data is acquired through relayed images, with physical findings described by the local doctor or nurse who is carrying out the exam for the remote consultant. Consulting physicians now not only have to deal with uncertainty about the patient’s condition, but they have to deal with added uncertainty of the quality of the data about the patient received via telemedicine. Some doctors feel possible defects in transmitted data may increase the risk of malpractice (Parsons 1994). Whether this problem will impact the use of telemedicine, and whether this added uncertainty results in an increase in the number of tests ordered, is yet to be shown (Holand & Pedersen 1993).

Several management issues concerned with the widespread use of telemedicine remain unresolved. Telemedicine requires that the consultant physician and the rural health worker be present with the patient at the same time. Because of the cost of communication and the staffing requirements to run the telemedicine system the efficient scheduling of the sessions at both sites is important. Another concern are the incentives for the physicians. Telemedicine consultations are more time-consuming than traditional consultations, and it is not clear if this difference will be reflected in the reimbursement structure for physicians.

The relative immaturity of evaluations in telemedicine give rise to concerns about its use. Some concerns are contradictory but exemplify the problems of introducing a technology into the medical system which does not simply make current work more efficient, but changes the practice of medicine. For example, doubts have been raised to whether introducing more tertiary care into rural areas will actually reduce the cost of health care, and whether telemedicine consultations will reduce the incentive for specialists to work in rural areas. On the other hand there is great hope that telemedicine services will provide a source of continuing education for country doctors (Akselsen & Lillehaug 1993).

Evaluations

Despite the interest and investment in telemedicine there are surprisingly few evaluations of the field (Brauer 1992). At this stage the telemedicine literature has many pilot study reports and subjective evaluations but few generalisable studies.

What factors are important to evaluate in a new medical technology? First, a new technology must have proven safety and efficacy. Second, the system must have clinical utility (Perednia 1993), this is addressed with such questions as “Is the system easy to use?”, “What effect does telemedicine have on the care of patients?”, “What is the most efficient use of telemedicine?”. Lastly, telemedicine must be cost-effective.

The issues of safety and efficacy require comparing the accuracy of diagnoses by telemedicine to some gold standard, for example, pathological diagnosis of biopsied material. This accuracy rate must be compared to the accuracy rate of “live” consultations.

Most telemedicine projects do not attempt to address the points discussed above. Formal studies of these questions requires a time frame beyond most pilot studies or proof-of-concept projects. The number of cases seen in most telemedicine projects is relatively small and it is hard, if not impossible, for one installation to collect a sample size of subjects that would produce statistically significant results (Allen 1994).

Another problem with interpreting telemedicine evaluations is the difference in technology that has been used over the years. Computer display, imaging, and compression techniques are improving rapidly so criticisms made 5 or more years ago may not be relevant today. It is difficult to apply lessons from many pilot projects that have been designed using “ideal” systems, such as very fast networks and very expensive imaging equipment. It is unlikely that the majority of telemedicine connections will use fast network technology until new wiring and switching equipment is installed in rural areas.

Telemedicine cooperative ventures are now forming to pool data from multiple telemedicine projects in an attempt to answer some of the questions raised in this section (From et al 1993,Perednia 1993) It is likely that clinically relevant and statistically significant data will be available in the near future.

Security

Patient confidentiality and the security of patient data is often ignored in pilot studies. As yet there have been no breaches of security reported (Parsons 1994) but unless the issues of data encryption and user authentication are addressed telemedicine will be susceptible to security problems which could set the industry back many years. (It is interesting to note that paper-based records are inherently more secure than digital data because paper records are so difficult to find and search even when one is looking for them.)

Looking ahead

Computer technology is doubling in speed every 12 to 18 months, and with this increased speed brings the promise of faster and less lossy compression techniques. Colour displays are still very expensive but in the long term cathode-ray displays will be replaced by some variety of liquid-crystal display technology which will not exhibit the same accuracy problems as tube-based displays when scaling up to larger sizes. High definition television (HDTV) promises a high-resolution digital standard for television which avoids the analog-to-digital conversion that is currently required. HDTV relies on image compression during picture transmission so the consumer production of HDTV systems will lower the price of large displays and compression hardware.

Networking technology is also increasing in speed very rapidly. Telephone systems are gradually being converted into fiber optical cable, and asynchronous transfer mode (ATM) appears to be the dominant networking technology of the future. ATM can deliver 155 Mbps to the desktop, and potentially deliver several gigabytes per second across wide area networks. Unfortunately it may be some time before rural connections are upgraded to provide ATM speeds. Another solution is to use copper-based T1 connections (1.5 Mbps) to major rural sites.

It is quite possible that the term “telemedicine” will be replaced simply by “teleconferencing”. Faster networks and cheaper hardware also mean that video and sound telecommunication is possible for non-medical businesses and consumers. As this technology becomes more widespread telemedicine may become a part of daily practice for many practitioners who have video and computer technology on their desktop, and connecting to remote physicians is as easy as a telephone call.

Conclusions

The growth of telemedicine has been hampered by high set-up costs, and by the paucity of quality data regarding many important questions which must be answered before the widespread introduction of the technology into the health care system. The rapidly falling prices of computer equipment mean that telemedicine projects are easier to initiate, but there are still valid concerns about the safety, efficacy, and security of telemedicine technology.

Telemedicine is an interesting case study in introducing a new technology that provides facilities not previously available, in this case, tertiary health to the rural sector. It is a mixture of many advanced technologies and the traditional practice of medicine.

Greater specialisation of medical graduates, and greater investment in tertiary centres has put pressure on the health care system to distribute services to rural areas which have been suffering a steady decline of health care resources. Telemedicine will be a useful tool in distributing services around the country, and possibly overseas. Until more evaluation data are available it remains to be seen how telemedicine must evolve to best suit the needs of medical practice.

References

Aberle D R, Gleeson F, Sayre J W et al 1993 The effect of irreversible image compression on diagnostic accuracy in thoracic imaging. Investigative Radiology 28(5): 398-403

Akselsen S, Lillehaug S I 1993 Teaching and learning aspects of remote medical consultations. Telektronikk 89(1): 42-7

Allen A 1994 Evaluating telemedicine: the cooperative model. Telemedicine Today 2(1): 8-9

Beard D V, Hemminger B M, Keefe B et al 1993 Real-time radiologist review of remote ultrasound using low-cost video and voice. Investigative Radiology 28(8): 732-4

Brauer G W 1992 Telehealth: the delayed revolution in health care. Medical Progress Through Technology 18(3): 151-63

CCITT 1990 Narrow-band visual telephone systems and terminal equipment No. H.320 International Telegraph and Telephone Consultative Committee, International Telecommunication Union, Geneva

Cosman P C, Davidson H C, Bergin C J et al 1994 Thoracic CT images: effect of lossy image compression on diagnostic accuracy. Radiology 190(2): 517-24

From S, Stenvold L A, Danielsen T 1993 Telemedicine services integrated into a health care network-analysis of communication needs in a regional health care system. Telektronikk 89(1): 12-22

Holand U, Pedersen S 1993 Quality requirements for telemedical services. Telektronikk 89(1): 51-3

Kajiwara K 1992 JPEG compression for PACS. Computer Methods and Programs in Biomedicine 37(4): 343-51

Keil-Slawik R, Plaisant C, Shneiderman B 1991 Remote direct manipulation: a case study of a telemedicine workstation. In H.-J. Bullinger (eds) Proceedings of the Fourth International Conference on Human-Computer Interaction, pp. 1006-11 Stuttgart, Germany, 1-6 Sept.: Elsevier, Amsterdam, Netherlands

Parsons D F 1994 Telemedicine in New York State No. nystelem.101 New York State Department of Health

Perednia D A 1993 A brief introduction to telemedicine system evaluation and the Clinical Telemedicine Cooperative Group (CTCG) No. Oregon Health Sciences University

Perednia D A, Gaines J A, Rossum A C 1992 Variability in physician assessment of lesions in cutaneous images and its implications for skin screening and computer-assisted diagnosis. Archives of Dermatology 128(3): 357-64

Sayre J W, Ho B K, Boechat M I et al 1992 Subperiosteal resorption: effect of full-frame image compression of hand radiographs on diagnostic accuracy. Radiology 185(2): 599-603

Scott W Jr., Rosenbaum J E, Ackerman S J et al 1993 Subtle orthopedic fractures: teleradiology workstation versus film interpretation. Radiology 187(3): 811-5

Wallace G K 1991 The JPEG Still Picture Compression Standard. Communications of the ACM 34(4): 30-44

Watson D S 1989 Telemedicine. Medical Journal of Australia 151(2): 62-6

Weinstein R S, Bloom K J, Krupinski E A et al 1992 Human performance studies of the video microscopy component of a dynamic telepathology system. Zentralbl Pathol 138(6): 399-403

Wilson D L 1992 Compressed radiological images and workstation viewing. Journal of Digitital Imaging 5(3): 168-75