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Technological Advances in Teleradiology

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Abstract

Teleradiology consists of a set of added-value telematic services, implemented over an advanced telecommunications infrastructure and supported by different information technologies and related applications. The main goal of teleradiology is to provide different levels of support for remote diagnostic imaging procedures. This paper considers technological advances in this important area, including a discussion of the various added-value telematic services, applications supporting these services, and the required information technology and telecommunications infrastructure. Teleradiology is also considered in the general context of an integrated regional health telematics network, emphasizing its role and its interaction with other information and networking services.

Keywords: teleradiology, health telematics, multimedia communications, computer supported cooperative work, asynchronous teleconsultation, synchronous teleconsultation, computerized patient record, patient meta-record.

1. Introduction

In recent years, advances in information technology and telecommunications have acted as catalysts for significant developments in the sector of health care. These technological advances have had a particularly strong impact in the field of medical imaging, where film radiographic techniques are gradually being replaced by digital imaging techniques, and this has provided an impetus to the development of integrated hospital information systems which support the digital transmission, storage, retrieval, analysis, and interpretation of distributed multimedia patient records (i.e. structured collections of attribute, text, image, and voice data) [1]. Thus, medical imaging has become an important application domain for the use and validation of new information and telecommunications technologies. In particular, these technologies are currently used to enhance the capabilities of all diagnostic medical imaging modalities and to provide added-value services to the health care community, with an aim toward improving the delivery of health care and ultimately patient outcome.

In the past two decades, diagnostic medical imaging has been revolutionized by a series of developments based on the use of different types of energy to probe the human body in order to obtain different anatomical and functional images. However, the possibility for yet another type of energy leading to the development of a new medical imaging modality appears to be rather remote. Thus, the main issues and challenges currently confronting the medical imaging community are listed and justified below:

1) Multimodality medical images contain a wealth of qualitative and quantitative diagnostic information, which is not being fully exploited in routine clinical practice. The development of advanced techniques for data fusion, synthetic imaging, and visualization is and will remain a challenge for the research community for many years. Quantitative tissue characterization, the quantification of hemodynamic parameters, and the measurement of other diagnostic indices, based on properly calibrated medical image data, are also issues of current research and clinical interest.

2) The efficient and intelligent management of the huge volume of multimedia patient data, currently generated by different hospital departments, is a practical issue whose successful resolution will undoubtedly have a strong impact on the timely and effective delivery of health care services. This is particularly true in the case of multimedia data which is geographically distributed at a local, regional, national, and transnational level. The development of methods and tools for navigating through multimodality three-dimensional image data is also an interesting research problem with important consequences for medical training, diagnostic decision making and therapeutic intervention. Current research on virtual reality, 3D video communication, image guided therapy, and surgical navigation is expected to yield some solutions in this particular area.

3) Using information technology and telecommunications to develop and make available added-value health telematics services to health care professionals and citizens is an additional issue, which is becoming increasingly important. Such services would make it possible for expertise to be a shared resource, wherever it may exist, and would eventually provide all citizens in urban and rural areas, as well as at remote and isolated sites (e.g. small islands, high mountains, ships at sea, etc.) with an adequate level of care based on the collective expertise of the wider medical community. Effective and efficient added-value telematics services would also partially justify the high cost of new technologies introduced in the hospital environment. Teleradiology, as a specific instance of telemedicine, is an added-value service of particular importance due to the subspecialization currently required in medical imaging, which makes expertise in the area represented by any one of the medical imaging modalities a rather scarce resource.

Teleradiology consists of a set of added-value telematic services, implemented over an advanced telecommunications infrastructure and supported by different information technologies and related applications. The main goal of teleradiology is to provide different levels of support for remote diagnostic imaging procedures. In this sense, teleradiology is much more than a "method for communicating diagnostic images and other relevant information between remotely located facilities, frequently by wide area networks", as suggested by the European Committee for Recommendation - Standards on Computer aspects of Diagnostic Imaging [2]. Rather than attempting another general definition, this paper considers technological advances in this important area, including a discussion of the various added-value telematic services, applications supporting these services, and the required information technology and telecommunications infrastructure. Teleradiology is also considered in the general context of an integrated regional health telematics network, emphasizing its role and its interaction with other information and networking services.

The basic services supported by an integrated teleradiology services network (ITSN) are: telediagnosis, teleconsultation, telemonitoring, and telemanagement. Other added-value services which can also be provided over an ITSN include access to high-performance computing facilities in order to execute computationally intensive image analysis and visualization tasks [1], information retrieval from remote databases containing material of reference and educational value, etc. The underlying technology of teleradiology services consists of transmitting and receiving workstations with appropriate user interfaces, an advanced telecommunications network, and teleradiology specific modules for synchronous teleconsultation, image processing, image management, etc. Although teleradiology services may be established on a point-to-point basis between single communicating nodes, in the case of large health care facilities, it is desirable that a PACS (Picture Archiving and Communication System) or IMACS (Image Management And Communication System) exist at both ends of a communications link. This would facilitate the management of local resources at the transmitting and/or receiving end.

The justification for the effort and cost of developing teleradiology services lies in the modern health care environment, which exhibits the following interesting characteristics [3-5]:

- Medical diagnosis is becoming increasingly dependent on the results of imaging and laboratory tests rather than clinical findings alone. For example, approximately 70% of patients admitted to a hospital require some form of diagnostic examination [3].

- New diagnostic imaging modalities require subspecialty medical personnel to guide image acquisition and produce the primary diagnostic report. This scientific and technological progress has increased the number and complexity of parameters which must be considered by medical professionals for proper health care delivery. Conferencing between personnel of different subspecialties is often required to arrive at an accurate final diagnosis and to plan the course of therapy. Thus, physical conferencing or teleconferencing and teleconsultation are becoming increasingly important in routine clinical practice.

- Technology is evolving rapidly, thus reducing the capital and operational cost of diagnostic equipment and hardware required for medical information systems. At the same time, the cost of medical personnel is increasing, accounting for up to 70% of the total health expenditures in the European Union [5].

- Modern lifestyle requires immediate medical support and increased quality of care in remote areas with a lower healthcare practitioner-to-population ratio, such as tourist resorts, oil plants, ships at sea, etc. Thus, the health care system is spreading outside major hospitals and other well-equipped medical facilities. To provide continued and seamless care, across different levels of the health care hierarchy, to an increasingly mobile population, health telematics networks and services are needed at a regional, national, and transnational level.

Due to the same reasons mentioned above, there currently exists conventional communication (e.g. correspondence, telephone, and fax) among health care providers. However, the frequency of communication required, stringent constraints on response time, and the increasing volume and complexity of multimedia information to be communicated make it difficult to manage such communications by conventional means, giving rise to the need for teleradiology and other advanced telematic services [3, 6-8]. The inadequacy of conventional communication processes is also highlighted in recent studies on user requirements in health care communications [9].

Potential benefits of teleradiology services include improved access to diagnostic imaging facilities, reduced costs (less travel and work-leave expenditures, etc.), reduced isolation for both patients and medical personnel, and improved quality of care through real-time diagnosis, advanced decision support tools, increased collaboration and continuous education, reduced loss of patient data, and direct access to remote computational facilities for advanced image processing and 3D visualization. The above benefits are likely to become evident after a transition period, during which users of teleradiology services receive proper training and learn to trust them, potential legal issues are resolved, and capital and operational costs are reduced, while service quality is improved with new technological developments.

2. The Computerized Health Care Environment

Technological advances in teleradiology cannot be considered independently of the revolutionary developments which have occurred in the past twenty years in the field of medical imaging, paving the way for an increasingly important role of information technology and telecommunications in health care. The diagnostic imaging department of the future will make extensive use of computer networks, mass storage devices, and sophisticated workstations at which humans and machines will interact, assisted by advanced information processing tools and techniques of knowledge engineering, to achieve integration of multimodality imaging data and expert medical knowledge [10]. In many modern diagnostic imaging departments, this development is already in progress [4]. Computer networks also provide physical links to other hospital departments and patient wards in order to improve interdepartmental communications and patient monitoring procedures. Picture archiving and communication systems (PACS) form the core of such an environment, responsible for the acquisition, storage, communication, display and manipulation of diagnostic medical images and related patient data [11]. Teleradiology services build upon and extend this environment to interhospital or hospital to point-of-need communications on a regional, national, or global scale. Therefore, teleradiology can be considered as an extended virtual radiology department that encompasses available physical and human resources over a wide region in order to support remote diagnostic procedures and patient management. Possible teleradiology scenarios at various geographical scales include:

- *Local area services* (within the same building or adjacent buildings of the same hospital)

The radiologist reviews images and provides primary reporting and real-time remote consultation for critical cases, e.g. patients in the intensive care unit, the emergency department, or the operating room. This effectively corresponds to teleradiology services offered using the resources of a local PACS.

- *Metropolitan area services* (within the same metropolitan area)

Imaging specialists in a major hospital offer consultation and provide support for specific diagnostic procedures to other hospitals and private physicians in the same metropolitan area.

- *Wide area or global services* (services cover an extended geographical region and may cross country borders)
    - Diagnostic imaging examinations carried out by primary care or rural physicians can be monitored by specialists in a major referral medical center, who can also provide consultation on the diagnostic interpretation of acquired images.
    - Radiologists in a hospital can consult with colleagues or subspecialists located in other hospitals.
    - Medical imaging specialists in a hospital may also provide support to mobile diagnostic imaging units or units at remote and isolated sites, which may or may not have a radiologist on board. This scenario is particularly important for areas with a poor medical coverage, such as off-shore oil plants, ships at sea, isolated islands, villages on high mountains, and areas of military operations [3].

Teleradiology services involve multimedia communications [12-14]. The basic component of the communication object is the diagnostic image. Additional medical and demographic patient data, the referring physician's comments, and the radiologist's report are of a textual type. Teleconsultation may also involve the real-time transmission of voice and video data, while video frames (image sequences) of dynamic diagnostic imaging procedures and patient monitoring sessions may also be included as part of the communication object. Current advances in the indexing and management of multimedia data are likely to impact future developments in teleradiology services and applications [15].

Finally, teleradiology services often involve the use of heterogeneous hardware and software systems. The degree to which such systems can be fully integrated will have a significant effect on the efficiency with which such services are provided and, consequently, on their effectiveness, acceptability and acceptance by the health care community. Thus, integration mechanisms based on a unified user interface, a unified computerized patient record, which may consist of geographically distributed segments, and intelligent distributed hierarchical storage management are absolutely important in any attempt at providing efficient teleradiology services in an integrated health care environment [11].

3. Technological Advances

If we adopt the definition of teleradiology as a set of added-value telematic services, implemented over an advanced telecommunications infrastructure and supported by different information technologies and related applications, then a generic discussion of technological advances in teleradiology is inherently a difficult task. This is due to the fact that advances have undoubtedly occurred in telecommunications, as well as in information technology and a number of relevant applications. However, whether or not these also constitute advances in teleradiology is an open question which can only be answered if both technical and clinical considerations are born in mind. On the other hand, given the current stage of developments in teleradiology, it may be premature to discuss such matters and to arrive at any definitive conclusions. This paper attempts to put some order into a rather complex situation, based on certain assumptions as to what constitutes the technological, and partially clinical, environment in which effective teleradiology services can realistically be provided and accepted by the medical community.

Figure 1
The three-layer structure of the environment in which teleradiology services are provided.

The emerging environment in which teleradiology services can be provided has a layered structure (Fig. 1). The top layer corresponds to the actual services provided, such as telediagnosis, telemonitoring, teleconsultation, telemanagement, and other added-value services. The second layer consists of all computer applications that provide the necessary communications and computer supported cooperative working environment for teleradiology services to be realized. Such applications include electronic mail, multimedia conferencing, synchronous and asynchronous consultation, interactive image analysis and visualization of 2D and 3D image data, tools for querying geographically distributed image and other data bases, and a variety of other applications which provide added-value information services. The bottom layer corresponds to the hardware and software infrastructure that supports the above applications and consists primarily of medical imaging equipment, workstations, the telecommunications network, and tools for the management of network and other resources. Technological advances in teleradiology are primarily related to the applications and infrastructure layers. The services layer involves mainly clinical matters, as well as procedural and legal issues.

3.1. Services

The primary goal of teleradiology is to provide support for remote expert consultation on locally acquired medical images. The achievement of this goal requires that the teleradiology services provided are adapted and, to some extent, emulate routine clinical practices in the radiology department. Therefore, they must provide support for expert guidance during image acquisition and the conferencing of medical personnel of various subspecialties. Different services are described below, based on the specific objectives of each teleradiology session.

Telediagnosis: Typically, this service involves asynchronous point-to-point communication and requires relatively simple applications and a minimum infrastructure. In response to a request by a remote site, which transmits all or selected images of a diagnostic examination, specialists at a major medical center review these images and return a diagnostic report to the requesting site. Telediagnosis is particularly useful for rural and other areas which are not well served by specialized medical personnel.

Telemonitoring: In most modern diagnostic imaging procedures, patient positioning and the process of image acquisition are important factors determining diagnostic image quality. Telemonitoring serves the need for expert supervision of image acquisition by a specific imaging modality. Furthermore, an expert can manipulate and view image data during the examination, thus being able to request additional images after issuing instructions on how to reposition the patient or adjust imaging parameters. Telemonitoring does not necessarily impose heavy demands on the application layer, as the transactions between different sites are of a simple nature. Specifically, video sequences of the examination room and the patient are transmitted to the expert, who monitors the procedure and interacts with the examination site through an image and voice data link. However, the requirement for real-time multimedia communication imposes additional technological demands on the available infrastructure.

Teleconsultation: In recent years, the number and complexity of biological signals, which can be recorded and also presented in the form of reconstructed images, has increased substantially. This has given rise to the need for subspecialization, which in turn has resulted in an increased demand for consultation among different medical experts. Providing a shared workspace among medical experts at remote and distant locations, is one of the main functions of the teleconsultation service. This service requires the synchronous viewing and manipulation of the same set of radiological images and other patient data, as well as the real-time exchange of comments among all parties involved in the session. It is evident that the synchronization of the media and procedures involved in a teleconsultation session requires various types of complex transactions and resource management mechanisms, thus imposing serious demands on the underlying applications. Furthermore, the real-time nature of the service and the volume of multimedia data exchanged require a technologically advanced infrastructure.

Teleradiology is not limited to the communication and collaboration between experts. Of increasing importance are added-value teleradiology services, which enable the sharing of a variety of other resources necessary for extending and improving the quality of diagnostic imaging procedures. For example, teleradiology can provide access to high-performance computer centers for advanced image processing and 3D visualization [1, 13, 16]. Other added-value teleradiology services involve information retrieval from remote databases of reference material, such as on-line medical publications and digital atlases of the human anatomy. Such an example is the Visible Human image database, released on the Internet, which provides reference images of various diagnostic modalities correlated with cryosection photographs [17]. The sharing of such information is a valuable medical decision support tool and promotes the continuing education of medical personnel. Distant learning in teleradiology can also be accomplished by special interactive tele-education sessions [18], through remote expert guidance on a case by case basis and the distribution of specially prepared educational material, such as hypermedia diagnostic imaging textbooks [19]. In the future, medical training has a lot to benefit from the development of wide area medical education environments over high speed networks [20].

Telemanagement: The combination of advanced telemonitoring and teleconsultation services, with remote resource sharing, offers the possibility for the telematic management of diagnostic and therapeutic procedures. This teleradiology service is likely to gain momentum in the future with parallel developments in the areas of virtual reality, 3D video communication, and telepresence [21]. It may then become possible for teleradiology to also support remote diagnostic imaging examinations, as well as image guided radiation therapy and surgery.

3.2. Applications

All teleradiology services presented above involve a mixture of multimedia data communication and computer supported cooperative work, ranging from the most demanding real-time synchronous communication to the simpler case of asynchronous communication and cooperation. The temporal characteristics of this information exchange and the type of data involved determine which applications are required to support a particular teleradiology service.

Electronic mail is by far the most widespread form of asynchronous digital data communications [22]. When used in teleradiology, it takes the form of multimedia mail composed of radiological images (still or moving), medical and demographical patient data, as well as the physician's comments, written or spoken. The preparation of the multimedia document on which teleradiology is based is of major importance. As a result, effort is currently devoted to defining the logical structure of the multimedia document for teleradiology services, implementing relevant standards such as the Open Document Architecture (ODA) [12]. Additional research involves architectures that define the temporal and spatial relationships among the various elements of a multimedia object [13]. Hypermedia formatting and structuring can also be applied to multimedia mail documents, in order to establish semantic relationships between different media and improve the process of reviewing and annotation [23, 24]. The asynchronous mode of communication suggests that electronic mail does not require high transfer rates and can be implemented over any networking infrastructure. When standard multimedia mail formats are used, teleradiology services based on electronic mail can be provided over widely spread public networks at a minimum cost (e.g. MIME standard format for multimedia mail over the Internet [22]). However, the use of electronic mail is limited to less critical situations, which are well served off-line by routine telediagnosis.

Videoconferencing allows the synchronous communication of audio and video signals among several parties. In the diagnostic imaging environment, audio signals typically correspond to spoken comments exchanged among medical professionals. Video signals, however, can originate from multiple sources, such as pictures of the patient and the medical personnel involved in a conference, pictures of medical documents, and diagnostic images viewed on a light-box or display monitor. Hence, videoconferencing applications in teleradiology typically support multi-channel video transmission [25, 26]. Individual video signals are mixed prior to transmission, while channel selectors are used to display the desired video at the receiving end. However, each channel has different transmission requirements [26]. For example, video communication among medical personnel is typically used only to view the other party and is the least demanding. On the other hand, patient monitoring requires relatively high resolution images so as to allow observation of posture and behavior, while the transmission must be at an adequate frame rate to capture patient movement. Bandwidth requirements are even higher for diagnostic image transmission, especially when the goal is primary diagnosis or when the session involves time-dependent radiological examinations which must be transmitted at high frame rates (e.g., cardiac ultrasound). In order to meet the above requirements at a reasonable cost, videoconferencing in teleradiology has been implemented over broadband analog communication networks for metropolitan area services [25]. However, this mode of communication cannot always guarantee image transmission of sufficient quality and fidelity for primary diagnosis. The current trend is to use standard digital networks (such as broadband ISDN) for both local and wide area audio and video communication. In this case, the digitization of the video signal may also result in some loss of information [26, 27]. As a result of the above constraints, traditional videoconferencing has a limited impact on teleradiology services, with the possible exception of telemonitoring and tele-education.

Computer supported teleconferencing applications have been developed in the field of computer supported cooperative work (CSCW) and are currently providing more effective support for teleradiology services [28, 29]. Such applications provide a virtual common workspace in which many users can view and manipulate multimedia data and exchange comments during a computer supported conference. Critical to the creation of a virtual conferencing environment is the real time response of the application to the actions of remote participants. This can be achieved by a combination of high performance networks and reduced data transmissions during the conference. However, in order to meet the requirement for scaleable and readily expandable teleradiology services, the underlying applications can not always rely on the availability of a high performance networking infrastructure. Therefore, the focus is on developing mechanisms to reduce data transmission during the conference. A common practice is to transmit the conference material (diagnostic images and other patient data) to all participants prior to the consultation session, in the form of multimedia electronic mail [26, 30, 31]. After the initiation of the conference, the prefetched data are synchronously displayed to all participants. During the conference, various tools are provided for the manipulation, annotation and processing of the radiological images, and for the exchange of comments. These operations generate the only synchronously transmitted data. Response time is also closely related to the architecture of the application [28, 29, 32-34]. In a centralized architecture, all user input is sent over the network to the application server and the output is multicasted to all local systems for display. However, this introduces a significant communication overhead and the current trend is to use replicated architectures, where a copy of the application is executed on every local workstation. Communication between applications is then limited to a minimum set of control messages for the update of the shared environment. A more important advantage, however, is that replicated architectures are better suited for the heterogeneous hardware environments encountered in teleradiology because each instance of the application can be tailored to the capabilities of the local workstation and the needs of the individual user. Current research in the field aims at the development of advanced, intelligent modules for the synchronization of the participants' actions, and the overall management and organization of the conference [13, 33, 35, 36].

Although computer supported conferencing applications suffice for typical teleconsultation sessions in teleradiology, added-value services such as telemanagement or interactive distant learning often require enhanced real time audio and video communication capabilities. Such services are best supported by multimedia desktop conferencing applications, which are essentially the fusion of videoconferencing and computer supported teleconferencing. The success of this integration is based on the synchronization of the real-time multimedia data streams, i.e. coordination and time ordering between the various data types [13, 35, 37-39]. Multimedia conferencing has increased requirements for both transmission bandwidth and data integrity. As a result, its successful implementation requires the use of high performance computing and networking environments [39, 40].

3.3. Infrastructure

The basic infrastructure required for teleradiology consists of medical imaging equipment, workstations, the telecommunications network, and tools for the management of network and other resources. Although distributed data archiving is essential for the efficient operation of teleradiology services, it ought to be a function of the local image management system (i.e., standalone image data base system, PACS or IMACS) that should ideally exist at sites involved in teleradiology. However, it is generally accepted that the teleradiology infrastructure also includes information systems responsible for short term storage and management of multimedia data [41] and able to implement strategies for intelligent data prefetching, as required by several applications mentioned above. In this section, important technological issues related to the teleradiology infrastructure, and other related issues such as image compression, data security and standardization, are considered and discussed.

Teleradiology workstations do not necessarily differ from other medical imaging workstations, other than to provide certain application specific functionalities. Medical imaging workstations can generally be classified into three main groups depending on the medical task for which they are intended [3]: 1) reporting workstations used to support primary diagnosis, 2) review workstations used for consultation and education, and 3) workstations for special applications supporting stereotactic neurosurgery, radiation treatment planning, intensive care units, etc. In general, medical imaging workstations require display monitors with a wide dynamic range [42], while their size and spatial resolution depends on the matrix size of displayed images [43, 44]. Thus, for radiation treatment planning [45] or emergency bed-side imaging [12], the resolution requirements are moderate, while high-resolution displays are mandatory for primary diagnosis [46-48]. Other important issues in the design and implementation of medical imaging workstations are the user interface and the required computational power.

All medical imaging and teleradiology tasks demand that displays are updated at sufficiently high rates, particularly when real-time image sequences are to be viewed. Such a requirement is met by advances in the processing power and user interfaces of computer systems. Teleradiology workstations are expected to heavily rely on the processing capabilities of the new generation of high performance computing platforms, which provide powerful image processing and compression capabilities, full motion video, and advanced graphics for high quality scientific visualization [49]. The effectiveness, efficiency, and acceptance of teleradiology services is also strongly dependent on the user interface of teleradiology workstations [48]. Thus, considerable effort has been devoted to user requirement analysis and interface design for teleradiology workstations [13, 14]. In the future, the development of adaptive and possibly intelligent user interfaces or interface agents, that can adapt to the specific requirements of an individual user and a particular task, may provide interesting solutions to problems related with the scheduling of teleconsultation sessions and the management of resources these may involve [50-52].

The telecommunications infrastructure involves transfer media, communication protocols, and network management mechanisms. The realization of a specific telecommunications network for teleradiology services depends on the specification of requirements such as data throughput rate, integrity and security, synchronization, priority control, cost, etc. To meet these requirements, appropriate network management strategies are mandatory [53]. Furthermore, the real-time communications required by most teleradiology services and the vast amount of multimedia data involved in related transactions result in excessive bandwidth demands per imaging modality, medical imaging workstation, and teleradiology session [4, 54, 55]. Bandwidth requirements and traffic characteristics for multimedia object communication and generic teleradiology applications are summarized in [40, 41]. Based on such data, modeling and simulation techniques are employed to estimate teleradiology workload, data throughput rates, as well as network capacity and performance for various communication infrastructures [6, 14, 54, 56]. ATM (asynchronous transfer mode) is often described as the technology that will allow total flexibility and efficiency to be achieved in high-speed, multi-service, multimedia networks of the future [57]. The expectation is that, by next decade, most of the multimedia data traffic generated in the world will be transmitted using ATM. Teleradiology services are already providing a testbed for experimenting with such a network technology [41]. However, the basic requirement that a teleradiology service is readily scaleable and expandable to include new sites suggests that, in many cases, hybrid network technologies are currently the only practical solution for teleradiology. Figure 2 shows one example of such a hybrid network architecture for cost-effective teleradiology services.

Research in medical image compression aims to minimize the number of bits per pixel required to represent digital images of various modalities, while maintaining an acceptable image quality for clinical use. Due to legal and medical implications, reversible or lossless compression is the currently acceptable method of medical image compression. Given that a variety of image compression techniques are available and are currently used in medical imaging, the choice of a particular compression scheme is a complex tradeoff of system and clinical requirements [58]. The availability of high performance, but lossy, compression techniques is sufficient motivation to define an objective measure of image quality in order to be able to set a legal standard for lossy radiological image compression [58]. However, similar limitations do not apply for video and audio signals that do not carry sensitive medical information, as for example in the case of telemonitoring. Different video coding and compression techniques are available for videoconferencing applications and have been implemented in software, hardware, or hybrid systems [39, 59]. Hardware implementations maximize performance, while implementations based on software emphasize flexibility and look promising in view of the new generation of high performance processors.

Key issues in the design and development of a teleradiology network infrastructure include information integrity during transmission, authentication of submitted images and related data, and protection from unauthorized access. Transmission errors in digital networks are compensated for by error detection and correction codes provided by the various levels of the network architecture [60]. Medical data secrecy and integrity can be ensured by standard techniques of cryptography, while message content and origin can be verified by authentication mechanisms [61]. An implementation of digital signature technology in teleradiology produced evidence that it is adequate for medical image authentication [62].

Figure 2
A graphical example illustrating combinations of network technologies for teleradiology, corresponding to common, cost-effective solutions as realized today.

As already stated, teleradiology services should be realized in a way that facilitates the inclusion of additional sites at all geographical scales and supporting all functionalities. It is also important that teleradiology services are integrated with other medical information systems and services. This requires standardization at the level of medical procedures, relevant information technology, and communication protocols [8, 63]. Health care specific standards involve the development of models for the medical environment and relate to the terminology, protocols, concepts and semantics of teleradiology procedures. Relevant work is performed by the TC-251 European Standardization Committee, and is primarily a responsibility of the medical discipline [8]. Standards related to the information technology deal with multimedia data models and communication messages encountered in applications supporting teleradiology services. Examples include standards for the medical multimedia document architecture and communication format (e.g. ODA and MIME), user interface issues (e.g. based on World Wide Web), as well as standards for transmission and communication control structures within the application layer of health care networks (e.g. HL7). Finally, the lower levels of the teleradiology communications infrastructure require standards related to generic and health specific multimedia telecommunications (e.g. DICOM). Extensive discussions on standards in health care information systems and in teleradiology applications have previously been reported in the literature [8, 9, 13, 40, 63, 64].

4. Teleradiology and Integrated Regional Health Telematics Networks

The health care organizational structure is naturally hierarchical and distributed, involving large urban referral medical centers and regional hospitals, medium size health care facilities, small clinics, and individual practitioners. The objective of this structure is to offer comprehensive medical care, at a local, regional, and national level, with continuity across different levels of the hierarchy. Although each medical center is autonomous and devoted to the delivery of a particular set of services, continuity of care requires that different medical centers, offering complementary services or different levels of expertise, exchange relevant patient data and operate in a cooperative working environment.

The physically distributed resources of the health care sector and the diverse requirements of different medical facilities and clinical departments require that specialized autonomous information systems are used to support different functionalities, while they interact transparently to the user as a federation of autonomous systems. The above approach to developing and managing regional health telematics applications ensures the transfer and integration of consistent information throughout a network of health care facilities, without imposing constraints on the operation of individual units.

Health care is an important telematics application domain in the emerging information society. In recent years, we have all been witnesses to the gradual transformation of health informatics into health telematics, a process which continues. For this transformation to be successful, a strategy is needed for the creation of an integrated health care information infrastructure, based on the functional and data integration of federated autonomous information systems. Furthermore, in developing such a strategy, one must also consider the need for integrating existing systems into the emerging infrastructure and using it to provide clinically significant added-value services that would justify its cost and ultimately benefit the patient. A fundamental problem for the establishment of a scaleable regional health telematics network is the development of an architecture and tools for the integration of specialized autonomous applications that, together with a shared patient record, will support the interoperability of function and services within a health care institution, the interconnection of different institutions, and the intelligent management of medical data within such an integrated network. From the technological point of view, the adoption of an open architecture and standards represents the only solution capable of ensuring the achievement of such objectives, allowing the integration of diverse system components through an incremental approach, consistent with evolving requirements. Through such an approach, individual information systems can be independently customized and their operation optimized with respect to the specific requirements of the functional units they serve.

Information systems responsible for the acquisition, storage, communication, display and manipulation of diagnostic medical images and related patient data are at the core of a digital diagnostic imaging environment and constitute important components of an integrated hospital information system. Teleradiology extends this environment, effectively creating a virtual diagnostic imaging department, which encompasses technical and human resources over a wide region. In this extended environment, routine diagnostic and patient management procedures can be carried out in real time using all available resources. However, tracking the segments of a patient's computerized medical record, which may be created in such a distributed environment, and providing mechanisms for their integration and use by all networked medical information systems is an important requirement, as this would facilitate standardized communication and diagnostic interpretation, as well as efficient patient management.

With the above in mind, the regional health telematics network, which is currently being developed by the Institute of Computer Science on the island of Crete, represents an attempt to provide an integrated environment for health care delivery and medical training across the island [11]. An important concept in implementing a specific integration strategy is the Patient Meta-Record (PMR) [11], which is being implemented using the Semantic Indexing System (SIS) [15], a tool for describing and documenting large evolving varieties of highly interrelated data, concepts and complex relationships. The PMR manages references to all of the physical information related to a patient throughout the *Integrated Regional Health Care System*, regardless of where such information may reside. Teleradiology is a fundamental service to be provided over the regional health telematics network and, thus, is being developed following the same strategy of an open, expandable and extensible architecture with various added-value autonomous modules supporting clinical decision making, medical training, and clinical research. Figure 3 shows a teleradiology session established among different nodes of a regional health telematics network, with different segments of a patient's computerized patient record integrated using the PMR concept.

Figure 3
Teleradiology session involving different nodes of a regional health telematics network.

Asynchronous telediagnosis is supported by the regional image management and communication system [11], which provides an integrated environment for the acquisition, management, communication, display, and processing of medical images at different hospital departments on the regional network. The communication between departmental systems is based on a multimedia e-mail application. A typical screen of this system with its e-mail application window, image browser, tree of a patient's diagnostic examinations, and image display and processing window is shown in Fig. 4. Synchronous teleconsultation is also possible via a computer supported teleconferencing application [65], which allows interactive real-time cooperation among several conference participants. This application provides a shared workspace for the display, discussion and annotation of multiple radiological images which are multicasted to conference participants prior to the consultation session. A replicated architecture and techniques for cashing, data compression and screening of events allow its successful operation over heterogeneous, relatively slow networks. These services gain added value through access to I^2C (Image Indexing by Content), an information system used for the description, management, and retrieval of diagnostic medical images based on their pictorial content [66]. I^2C is currently being extended to I^2Cnet, a network of I^2C servers and clients, which will support content-based similarity search in geographically distributed repositories of medical images through a World Wide Web browser [67].

Figure 4
A typical screen of a system for the acquisition, management, processing and communication of medical images, with its multimedia e-mail application window [11].

5. Conclusions - Future Trends

This paper has considered technological advances with respect to the applications and infrastructure required to support teleradiology services. These technological advances are tightly coupled to recent developments in the fields of medical imaging, information technology, and telecommunications. The emerging environment is one which will allow integrated telematic services in health care to become a reality in the not too distant future. The health care sector will then have become an important domain in which to evaluate the real impact of the new information, and hopefully informed, society.

The past two decades have undoubtedly been characterized by important technological advances in information technology and telecommunications. These have also acted as catalysts for equally important developments in the fields of medical imaging, medical informatics, and health telematics. In the future, further technological advances will ensure the convergence and standardization of technologies used to provide integrated health telematics services, and will contribute toward their universal accessibility. The adoption of a distributed multimedia computerized patient record (CPR), with a patient meta-record (PMR) used to integrate the various CPR segments, is likely to play a central role in developing a common approach toward the provision of integrated health telematic services. Other technological advances which are expected to feature in these developments include, but are not limited to, virtual reality and telepresence, multimedia workstations with real-time resource management capabilities and advanced synchronization mechanisms for multimedia data components [39], unified user interfaces for all [68], intelligent browsing and data storage and retrieval strategies, high-speed communications supported by a fixed and mobile networking infrastructure, advanced network management techniques, and many more. Many of these technologies are at an advanced stage of development and are expected to impact teleradiology and other health telematic services sooner rather than later. The introduction of such integrated systems and services into routine clinical practice is a complex issue, whose successful resolution will require the close cooperation of technology providers and health care professionals. Then, patients will hopefully also experience the benefits of the above technological advances.

It is rather difficult to predict what the future has in store for society as a whole and health care in particular. We are just now beginning to get a glimpse of our digital future. However, there is little doubt that telematic services will be revolutionized by current, and not future, developments in information technology and telecommunications. The essentially infinite bandwidth provided by optical fibers, the currently achievable data transmission rates of several megabits per second through standard copper telephone wires reaching every home, the so called “Negroponte Switch” or trading of places between wired and wireless communications [69], which would make additional bandwidth available for communications between mobile units and the fixed telecommunications network, the development of substantially more powerful workstations or clusters of workstations, the design of ever more intelligent user interfaces and data retrieval strategies, and rapid developments in the area of multimedia data management and communications are already leading the way in the drive toward the creation of an environment which will support effective and efficient health telematic services. The challenge is to keep up with these developments and to be creative in using this emerging information technology and telecommunications infrastructure to provide clinically significant and cost-effective added-value telematic services to the health care community, while ensuring that the potential benefit to be derived from technological advances also finds its way to the scene of an accident or the home of patients and the elderly.

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