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The Evolution of a German Teleradiology System

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Abstract

This paper describes the evolution of a german teleradiology system. The development started from simple image file transfer, continued with a dedicated teleradiology system and ended up with a general radiology workstation with teleradiology features. The main features, advantages and drawbacks of the different generations are described. The own developments are compared with developments at other places. The influence by standards is also included in this investigation. The latest systems are mainly used by the radiologists and the image transfer for scientific cooperation is nowadays just one of several application fields of teleradiology.

Keywords

Teleradiology; Telemedicine; Computer supported cooperative work (CSCW); PACS; Image Processing; Radiology;

Introduction

The main research interest of the Division Medical and Biological Informatics at the German Cancer Research Center (Deutsches Krebsforschungszentrum) in Heidelberg, Germany, is medical image analysis [1]. The division is active in this field since more than fifteen years now. Examples for our work are the Heidelberg Raytracing Method, which is a volume renderer for the 3 dimensional visualization of medical data, like sequences of CT or MRI images. Other examples of our work are the detection of tumors in the female breast, in the prostate, in the liver, and in the human heart. To be able to develop new methods in this field it is absolutely mandatory to have access to clinically relevant images. Just some example sets of images may be sufficient to start with the development of a new image analysis method. But studies of many patients are necessary for real evaluations.

The transfer of some example images can be managed with floppy discs or WORMs. More automatic and computer based image transfers are necessary to be able to handle for example 200 patient studies with more than 100 MB each. We started to work in the field of teleradiology with the main goal to be able to get huge data sets of clinically relevant images from the modalities in the clinic to the image processing research lab.

Step 1: Image file transfer via ISDN (1992-1994)

Our teleradiology activities started in 1992 in a small project MEDICUS which was funded by the German Telekom [2]. An MRI scanner (Philips T5) in a private radiology practice has been connected to a PC which transferred the images to the German Cancer Research Center. The computer of the MRI was a VAXstation running VMS. As no TCP/IP protocol was available on this system, we used DECnet as network protocol. The PathWorks product (Digital Equipment Corp.) had to be installed on the PC, which was equipped with an ethernet card. Windows 3.1 was the operating system of the PC.

The DECnet configuration of the MRI console had to be done in cooperation with the technicians of the vendor. The system had already an export function which could convert images from the internal format to ACR/NEMA 2.0 and store them in a local file system. We wrote our own transfer programs which transferred new data in the export directory automatically to the PC using DECnet remote copy functions.

The transfer from the PC at the radiology practice to the Cancer Center was realized via ISDN. Both PCs were equipped with ISDN cards (Fa. Teles). An ISDN specific remote copy program was used to transfer the image files to the other PC at the cancer center. The images could then be distributed in the LAN to UNIX workstations where the images were processed.

Results

The advantage of this solution was that it could be solved with a number of standard software and hardware products and about one man month additional programming. It was relatively inexpensive. But the system had some drawbacks:

- The transfer software at the console of the MRI disappeared, when the technicians simply exchanged the computer because there was a hardware failure. The DECnet configurations vanished also from time to time, when new software versions were installed on the MRI. Special procedures had been worked out with the (very cooperative) technicians to solve this problem.
- The ACR/NEMA file names under VMS were quite long. They had to be mapped from 20 to eight characters in a (hopefully) unique way.

- A PC program fetched the images from the MRI. It was blocked for other activities in that mode.
- The receiving PC at the cancer center had to be brought to an ISDN server mode to be able to receive images. Both PCs were blocked during the image transfer.
- It happened very often that the different PC software components for teleradiology did no longer work after the installation of additional software or extension cards, which were not compatible with the existing Ethernet and ISDN boards. Another source of problems were users who changed the system configuration files (like config.sys or autoexec.bat).

This configuration was operational for more than two years and about 100 MRI patient studies (with 34 MB each) were transferred to the research lab.

Discussion

People in other countries also worked on their first approaches to teleradiology. Grigsby gives an overview about the state of teleradiology in the United States in 1994 [3]. Similar systems have been developed and used in Europe, e.g. [4,5,6]. Regular telephone lines and modems were normally used at that time. Most of the developed systems were based on Personal Computers using video cameras with PC frame grabber cards or scanners to capture the images, e.g. [4,5]. Often discussed topics in the field of teleradiology are spatial resolution and gray-value depth of the video images or scanners. But this problem does not exist, when the original digital images are processed, as in our case. The receiver gets the images in original quality.

Conclusion

The advantage of our system was that we got the digital image data with 12 bit pixel depth without any loss. This is a need for advanced image analysis procedures. This first teleradiology solution needed many manual procedures and it was not very reliable as described above. Furthermore, it was dependent of vendor specific hardware/software configurations. It was not possible to send the results back and to have teleconferences on the original and processed image series.

Step 2: The dedicated Teleradiology System MEDICUS (1994 - 1996)

A dedicated teleradiology system MEDICUS has been developed in cooperation with the Steinbeis Transfer Center for Medical Informatics in the MEDICUS-2 project from mid 1994 until mid 1996. It was funded by the DeTeBerkom, a subsidiary of the German Telekom [7]. Our goal was to develop a system which was more stable than the first solution and which would offer a broader spectrum of functions to the users. A system analysis was performed to find out the needs of the future users. The result was that the users wanted asynchronous file transfer without blocking of the computer or image viewer. Teleconferences should be possible where both users see the same image in the same level/window setting and where both can work simultaneously on the shared images. The cursor of the remote site should also be visible in the cooperative session. A basic requirement was that the images should have the original image quality. Data security was another strong demand. Live video images of the conference partner was not requested by our users [7,8].

A definition of teleradiology was not available until 1994, when our project started. The American College of Radiology ACR defined it in the "ACR Standard for Teleradiology" [9]. This resolution includes an initial definition of teleradiology (besides goals, qualifications of personnel, equipment guidelines, licensing, credentialing, liability, communication, quality control, and quality improvement for teleradiology). The ACR definition of teleradiology states the following [9]:

"Teleradiology is the electronic transmission of radiological images from one location to another for the purposes of interpretation and/or consultation. Teleradiology may allow even more timely interpretation of radiological images and give greater access to secondary consultations and to improved continuing education. Users in different locations may simultaneously view images. Appropriately utilized, teleradiology can improve access to quality radiological interpretations and thus significantly improve patient care.

Teleradiology is not appropriate if the available teleradiology system does not provide images of sufficient quality to perform the indicated task. When a teleradiology system is used to produce the official authenticated written interpretation, there should not be a significant loss of spatial or contrast resolution from image acquisition through transmission to final image display. For transmission of images for display use only, the image quality should be sufficient to satisfy the needs of the clinical circumstance."

Since this standard should serve as a model for all physicians and health care workers who utilize teleradiology, we used it to design the MEDICUS application.

The MEDICUS teleradiology system

We developed the MEDICUS teleradiology system according to the requirements of the users, the ACR, the German laws and our own ideas based on the experiences we gained with the first system. Key features of MEDICUS are:

- The system is independent of the physical network layer, such as ISDN, Ethernet or ATM. The communication protocol of the system uses the *TCP/IP* standard.
- The system is based on the *UNIX* operating system which has the best connectivity features today. Security concerns and robustness of the operating system were other reasons.
- The system is *portable* to different UNIX hardware/software systems. Development platforms are the Silicon Graphics Indy workstation and Linux PC's.
- The *graphical user interface* is based on results of cognitive psychology and a medical style guide for efficient medical user interfaces [10].
- *Digital imaging modalities* are directly connected to the MEDICUS system. The image transfer works in the background without user interaction. MEDICUS supports the *image communication and file standards* ACR/

NEMA and DICOM [11]. As propriety formats exist in the field, processing these formats, as well, cannot be avoided. *Other image sources* are supported. Images can be captured from various video sources, e.g. camera, video recorders, ultra sound scanners.

- As huge data sets have to be processed, it is not possible to do the data transfer during cooperative sessions. Therefore, the data transfer is performed before the session (during less expensive hours). Additionally, it is possible to capture and submit image data during a teleconference.
- All data in the MEDICUS system are stored in *patient data bases*. The user can access the images for example by patient name, patient id, study date or study id.
- *Data protection and security*: Since image data contain patient information, data protection issues become relevant with the application of this teleradiology system. A concept was developed which unites the data privacy requirements stipulated by German law (Bundesdatenschutzgesetz, BDSG) and the technical aspects of data security. The European and German recommendations for the establishment of IT security concepts have been used [12]. Local data are encrypted with a symmetric encryption algorithm and shared data are encrypted with the public key encryption system PGP. Digital signatures and checksum methods are used to protect integrity and authentication.
- *Viewing Station Functionality:* As the image data are available at the MEDICUS workstation it is possible to use it as a classical viewing station as well. Several workstations can be distributed in the hospital and share the disk of one central system.

Results

Thirteen medical sites were equipped with Silicon Graphics Indy workstations and the MEDICUS software at the end of 1995. All medical partners were located in Germany: in the south west (Heidelberg/Mannheim area), in the north west (Essen/Velbert) and in the south east (Nuremberg). Eleven different imaging modalities of five different vendors were connected to the system using the DICOM protocol or TCP/IP and DECnet based transfer programs. All machines were connected to a standard ISDN S_0 plug. The first month were used to test the system and to train the users. Clinical routine use started in spring 1996. A hotline for user support has been set up at that time. Built-in logging functions have been implemented to collect data about the system usage. Electronic questionnaires were integrated into the application to find out more about the experiences and expectations of the users.

The system functions have been logged and users answered the questionnaires from June 1996 until June 1997. The program has been used more than 5,000 times and about 55,000 images have been processed during that time. Nearly thousand patient studies have been handled with our system. About 200 teleconferences were executed. Both, physicians and patients profited from quality improvements and an accelerated diagnostic process. The users reported financial advantages due to the usage of the teleradiology system.

Discussion

A prototype of a dedicated teleradiology system has been developed by Gomez and co-workers in a research project funded by the EU AIM Programme [13]. The system has been evaluated in two hospitals in Spain. One imaging modality was connected to one of two teleradiology workstations. Handels describes another German teleradiology system, called KAMEDIN, which has been used in a field test for several month but never went to clinical routine [14].

All major image modality vendors in the field of radiology started to talk about teleradiology since 1994 or 1995. The main difference of industrial solutions is that they simply extend the local area network of the radiology department by an ISDN link to another location. Images are then sent with propriety protocols (sometimes with DICOM) to a remote machine. Teleconferences with two users at different locations who work together on the same images are not possible. Security aspects are missing as well.

MEDICUS seems to be the only systems which has a complete data security concept. A great advantage of the system, compared to others, is the direct connection with the imaging modalities of different vendors. The DICOM protocol could be used to receive the images as well as propriety solutions for older modalities without DICOM interfaces.

MEDICUS-2 was not just a research project where the system was in use for some test cases. It is integrated in the clinical routine in more than ten different locations in private practices, small hospitals, university clinics and research institutions.

Although the experiences with the system were quite positive we could see that the system could be improved. A major observation was, that MEDICUS became also a viewing station in the radiology department. The users asked for additional functions, like printing on laser printers or laser imagers. They wanted to send images also to viewing stations of other vendors or retrieve images from the PACS archive.

MEDICUS was designed to be a dedicated teleradiology system. The main functions were image reception from modalities, image transmission to other locations, teleconferencing and (synchronized) image viewing. The next generation should be a general purpose viewing station with teleradiology functions [8,15].

Step 3: The commercial Teleradiology System CHILI® (since 1996)

By mid-1996, the Steinbeis Transfer Center for Medical Informatics in Heidelberg, Germany, began developing a commercial successor of MEDICUS in cooperation with the German Cancer Research Center. System design and development were based on the concepts and experiences of the MEDICUS project. The requirements for the second generation system have carefully been collected and integrated into the new concept. CHILI is a completely new implementation. The result is a modular architecture of components that can be integrated into packages for the specific needs of users. These are the key features of the second generation teleradiology system CHILI [16]:

- *DICOM Functionality:* DICOM is the basic communication protocol and image file format for receiving images from the imaging modalities. The system is able to capture videos from connected video cameras or other video sources. Images can be sent to viewing stations, imaging modalities, film printers and other devices via DICOM. The DICOM protocol is used for the distribution of images to other teleradiology systems. Query and Retrieve functions are available to get images from modalities and digital archives. Image printouts on film and paper are supported (via DICOM as well).
- *Viewing Functionality:* The kernel of the system is a general purpose radiology image workstation that can be used for reporting and viewing images, is connected to imaging modalities and has access to a digital image archive. The ergonomic user interface is based on results obtained in human computer interface research. The interface supports both inexperienced beginners and skilled experts who use the system in their daily routine [16]. Small-matrix images (CT, MRI, ultrasound, nuclear medicine, digital fluorography), large-matrix images (e.g., digitized radiographic films or computed radiography) and image sequences such as cardiac image sequences can be displayed and processed. Different monitor options are available to match the actual requirements of the application scenario (e.g., reporting, reviewing, presentation).
- Data and functions are synchronized during *teleconferences*. The communication partner's cursor is also visible on the screen. Both users have full access to all viewing functions. It is possible to capture and transmit video images during teleconferences.
- The *database* interface is easy to use both for query/retrieval of ·cal data on the workstation and for external data in digital PACS archives or imaging modalities. Supported standards are SQL, ODBC, JDBC and DICOM.
- *Client/server configurations* are possible in a local area network where one workstation can act as a central server for data storage and distribution and a number of smaller clients can access the central server for viewing and teleconferences without prior image distribution to the conference partners.
- *Multiple platforms*: The system supports the UNIX world as well as the PC world (Windows 95 and Windows NT). Image transfer and teleconferences are possible across both worlds.
- *Extensibility*: New modules (plug-ins) can be added for additional software functions (e.g., dynamic MRI, 3D reconstruction, etc.). A developer toolkit allows the users (or other software vendors) to write their own plug-ins.
- *Internationalization*: The teleradiology systems of the second generation is customizable for different countries with respect to languages, data representation and specific cultural differences.
- The systems provides *network and software security* protocols to protect the confidentiality of the patient images and data. The security concept takes care of technical, educational, organizational and software aspects as already developed for MEDICUS [12].

Results

The first systems have been sold and installed in 1997. The participants of the MEDICUS network have been upgraded to CHILI in 1997. Twenty two systems are currently used in clinical routine (Dec. 1997). More installations are planned.

Discussion

A very important feature is the plug-in mechanism which allows the extension of the application even by end users without any changes of the existing software. Plug-ins are under development for advanced image analysis functions in several research groups in Germany. A plug-in with an interface to a radiology information system (RADOS M) was a first step to the integration of HIS/RIS/PACS which will be the challenge for the future. The established and implemented data security concept is a unique feature of the system. The usage of standards and de-facto standards (ANSI C, X11, OSF/Motif, SQL, ODBC, JDBC, DICOM, Unix and Windows NT) protect the investments of the users.

Conclusion

Our activities in the field of teleradiology started to support our own work for the purpose of scientific image analysis. We ended up, currently, with a general purpose radiology workstation. The system can be used as well for the distribution and cooperative discussion of medical images in local area (departmental) networks as over wide area networks for the cooperation with other doctors or clinics. It is also the platform for newly developed image analysis methods. Thus, image analysis functions (realized as plug-ins) can easier be brought to the physicians and are immediately integrated in the clinical routine environment. With this approach we have gained many advantages at the same time. More advantages can be expected as the development does not stop now.

A major result of our evolution is that it does not make sense to develop dedicated teleradiology systems. The communication and conference features must be a part of a general purpose radiology workstation, which must be integrated with the picture archiving and communication system PACS, the radiology information system RIS and hospital information system HIS. A distributed electronic patient record is necessary for an integrated system. Workflow management functions (not only in the radiology department) are necessary in the future. Extensions of the DICOM/MEDICOM standard have already been proposed [17] as a basis for distributed radiology where the radiologist on call can even access RIS and HIS data in an integrated manner at his remote workstation at home. The integration with the distributed electronic patient record will improve the currently available tools and make them quite more practical and efficient. The patient will profit by reduced costs and more efficiency of the health care system.

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