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Teleradiology System MEDICUS: Software Architecture and First Experiences

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Abstract. This paper gives an introduction to the teleradiology system MEDICUS which has been developed at the Deutsches Krebsforschungszentrum (German Cancer Research Center) in Heidelberg, Germany. The system is designed to work on ISDN lines as well as in a local area network. The global software architecture is explained in the article. Special attention has been given to the design of the user interface and data security, integrity and authentication. The software has been evaluated in a field test in Germany at 15 radiology departments in university clinics, small hospitals, private practices, and research institutes. First experiences show that the system is easy to use and can save time, patient transports and reduce film costs. It is well suited for remote consultation or for sharing resources, such as expensive equipments or radiologists.

1. Introduction

MEDICUS-2 is a project of the German Cancer Research Center (Deutsches Krebsforschungszentrum in Heidelberg, Germany). It is funded by DeTeBerkom in Berlin (a subsidiary of German Telekom). The project is carried out in cooperation with the Steinbeis-Transferzentrum für Medizinische Informatik in Heidelberg which is a transfer center for new technology in medical informatics. The project runs from August 1994 until July 1996. The goal of the project is to develop a teleradiology system that allows radiologists to submit images over ISDN (Integrated Services Digital Networks) and to perform cooperative work (two or more radiologists) on the same image data.

The motivation for the project is the expectation that a teleradiology system can reduce film costs, patient transports and travels of the radiologists. The quality of health care should be improved through faster and better diagnosis as remote experts can be consulted for complicated cases. Another expected advantage could be reduction of costs through resource sharing of expensive equipments and radiologists (e.g. during night shifts). It might be possible for radiologists to diagnose images after office hours from a computer at home. The following principle application scenarios for a teleradiology system could be identified after an extensive systems analysis at the beginning of the project:

1. *Remote consultation* of experts.
2. *Information exchange* with other treating physicians; joint therapy planning.
3. *Clinical cooperation*: Teleconferences with other researchers.
4. *Processing on demand*: Digital image analysis with a remote program on a remote

machine.
5. *Resource sharing*: Sharing of expensive hardware and experts.

2. State of the Art

A number of commercial products for computer-supported cooperative work, CSCW, are already on the market. Therefore, it had to be investigated whether the available products are able to satisfy the special demands of our users. Another guideline for this analysis was the ACR Standard for Teleradiology, which has been defined by the American College of Radiology [3].

The functionality of such products can be summarized as *video telephony* (to see each other and talk to each other), working on a common work area or *whiteboard* (e.g. drawing, writing, display of images, manipulation of 3D objects) and *application sharing*. Examples of such products are ProShare™ (Intel), InPerson™ (Silicon Graphics Inc.), X/Telescreen (VisualTek Solutions Inc.), Communique™ (Insoft), PictureTel Live™ (PictureTel), HP/MPower/SharedX™ (Hewlett Packard) and ShowMe™ (SUN).

An analysis of these products showed that all of them lack domain-specific functionality for the processing of digital radiographic images. They do not support the medical image standards ACR/NEMA[1] or DICOM[2]. It is not possible to handle 12-bit images and they have no specific functions for level/window manipulation or the analysis of gray values. Other functions for image analysis and processing are missing as well. Other drawbacks are that they are not integrated in the existing environment of a radiology department (connection with imaging modality; management of patient data and organizational data). Application sharing systems have the drawback that the submission of complete image series (up to 30 MB) over an ISDN line (2 B-channels, 64 Kbit/sec each) is too slow for efficient *interactive* cooperative sessions.

Non-commercial research systems like KAMEDIN [4] did not meet our user requirements or where not compliant with the ACR Standard for Teleradiology [3]. Thus, we decided to develop a new teleradiology system MEDICUS.

3. Basic operation principle of MEDICUS

Images from different sources (e.g. digital modalities, video cameras, document scanners) can be imported into MEDICUS. The transfer of the image data from a MR or CT scanner to the MEDICUS workstation is automated as much as possible, that the medical personnel can just invoke the standard export function on the CT or MR console to start the transfer process. The transfer process is based on TCP/IP or DECnet and is triggered by the exported data or invoked with one command at the console.

The transferred image data are placed in an *import file system* of the MEDICUS workstation. A daemon process checks this directory periodically and converts new data (from ACR/NEMA, DICOM, SOMATOM or MAGNETOM) to the internal format of MEDICUS which is a meta format to the existing standards [6]. The header information of the image files is evaluated to store the images with the accompanying alphanumeric information in the *Imported Data Base*. The MEDICUS program organizes the image data in a by Study ID, Patient Names, Image Series, Image No. etc. Thus, the user sees the data in an organization similar to that in his CT/MR console. Users are not confronted with the operating system, cryptic file names or transfer programs like ftp.

Image data can be submitted with three mouse clicks to a different machine. The clicks are necessary to identify the study (click 1), to select the addressee (click 2), and to activate

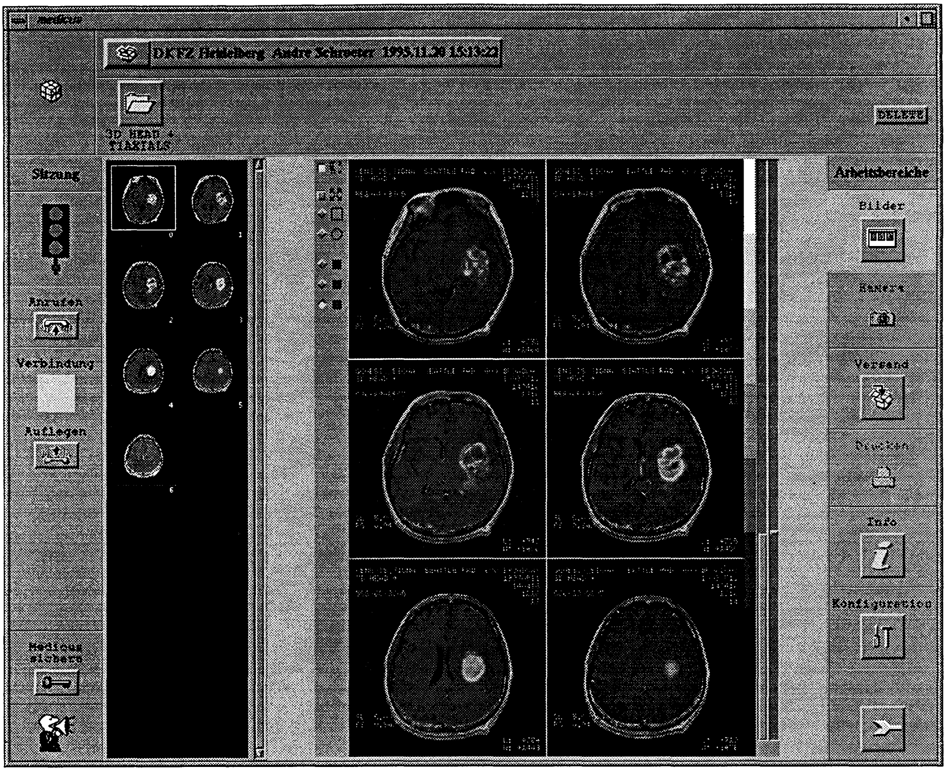

Fig. 1: User interface of the MEDICUS application

the submission (click 3). The user can select a subset of images and write a covering letter which will be sent with the images. Image data are collected in *folders*. Several folders are collected in *packets*. The packet is sent to the communication partner. It is possible to restrict the rights of the addressee on the image data. The following restrictions are possible: (i) Only viewable in a teleconference with the sender, (ii) Automatic removal after the teleconference. The packet is encrypted with a public key encryption system PGP [7]. The public key of the addressee is used for the encryption. The packet is signed with the digital signature of the sender and a checksum of the data is calculated. This protects data integrity, authentication of the sender and privacy for the receiver.

The data are internally buffered in a *Transfer Data Base,* where they wait for submission at a user defined date. The transfer process copies the data to the target machine into a *Shared Data Base*. The data are also stored locally in a *Shared Data Base*, when the remote machine has acknowledged the transfer. The data transfer is usually done off-line, because a typical data set contains several MegaBytes of data, which can take up to hours on an ISDN line. One CT image (512 by 512 pixel, 2 bytes/pixel) can be transferred over an ISDN line with two B-Channels (64 Kbit/sec) in about 33 seconds without compression. Typical image series have 30 to 60 images, sometimes more than 240 images in the case of MR mammography. A teleconference is initiated by a telephone call. The conference partners invoke the MEDICUS application (see figure 1) and one of the partners selects the other to establish the connection. The establishment of the ISDN connection is done automatically by the system. Both partners see the same shared data which where sent between them. Both can open packets and select images. Images can be displayed in different ways (e.g. normal size, magnified, 4 or 6 images side by side). It is possible to analyse the grayvalues and regions of interest (area, density values). A portion of the image can be magnified. The viewable grayvalue range can be changed analogous to the classical level/window function of CT or MR consoles. The image data and interactive manipulations on the images are synchronized during the cooperative session that both partners see exactly the same on the screen. The mouse cursors of both partners are visible.

4. Key features of MEDICUS

The MEDICUS system is based on the following key features, which are based on global design decisions which have been made before the start of the system design and implementation:

- *ISDN* is the physical target network. A standard S_0 telephone plug is used to communicate with the basic rate interface (BRI) of the computer. Bandwidth of one ISDN interface is divided into two 64 Kbit/s B-Channels and one 16 Kbit/s D-channel for signaling information. Supported protocols in Germany are the old 1TR6 and the new Euro-ISDN protocol DSS-1 (or NET-3).
- The system is based on the *UNIX* operating system. The reason is that it is mainly a communication system. The best connectivity features are found on UNIX systems today.
- *Standard protocols* are used for interprocess communication. TCP/IP is used in conjunction with PPP (point to point protocol) on the ISDN line.
- *Portability*: The system is portable to different UNIX hardware/software systems. Development platforms are the Silicon Graphics INDY workstation and LINUX PC's. SPARCstations under SunOS/Solaris, DECstations under Ultrix, DEC AXP-Systems under DIGTAL UNIX and HP systems under HP/UX are supported as well.
- *Programming and development tools*: The system is programmed in ANSI C. The user interface is based on X11/R5 and OSF/Motif 1.2. No GUI tool has been used to avoid dependencies of such a tool and to protect the portability of the system. Some GNU tools are used (e.g. dbm).
- The *graphical user interface* is based on results of cognitive psychology and a medical style guide for efficient medical user interfaces[5]. The system is based on the X Window System and OSF/Motif. The user interface is easily extensible.
- The user is able to work with the system without having any knowledge of an operating system and has no contact with Unix file system or commands. Instead, the system presents the information in known medical concepts, such as patients, studies, examinations and images. Existing functions (e.g. level/window manipulations) of the CT or MR console are also available in the system.
- *Digital imaging modalities* are directly connected to the MEDICUS system. The image transfer works in the background without user interaction (where possible).
- MEDICUS supports the *image communication and file standards* ACR/NEMA [1] and DICOM [2]. As propriety formats exist in the field, processing these formats, as well, cannot be avoided (e.g. SOMATOM, MAGNETOM).
- Other *image source* are supported. Images can be captured from various video sources, e.g. camera, video recorders, ultra sound scanners. The open interface allows an extension of the input sources.
- *Off-line data transfer*: As huge data sets have to be processed, it is not feasible to do the data transfer during cooperative sessions. Thus, the data transfer will be performed before the session (during less expensive hours). The data will be collected in *Packets* and *Folders*.

- *On-line data transfer*: It is possible to capture and submit image data during a teleconference. A connected video camera is able to acquire images and data from film or other documents.
- All data in the MEDICUS system are stored in *data bases*. The MEDICUS data bases are based on ndbm, a portable shareware database standard.
- The *communication* is based on TCP/IP and sockets [8]. The central entity which manages all aspects of interprocess communication is the *multiplexer*. Service components have been developed around the multiplexer: Transfer Service, Multicast Service, Info Service and Dial/Hang-up Service.
- *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. Local data are encrypted with a symmetric encryption algorithm and shared data are encrypted with the public key encryption system PGP[7]. Digital signatures and checksum methods are used to protect integrity and authentication.

5. First experiences

The first version of the MEDICUS system has been developed. It is compliant to the Standard for Teleradiology of the American College of Radiology. Approximately ten radiologists have been using it now (1/96) for two months. The system is running in a stable manner. All users say that the user interface is easy to use; even for non computer experts. First experiences show that the users could reduce travels, film costs and patient transports. The communication between the treating physicians can be improved with regard to both efficiency and quality. A detailed evaluation of the system, costs and general impact will be evaluated in the next project phase (2/96-7/96).

6. Summary

MEDICUS is a portable, easy to use teleradiology system which is based on standards for communication and medical image exchange. A field test is currently running to evaluate the system performance as well as the financial impact on the entire health system.

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