ELSEVIER Computer Methods and Programs in Biomedicine 54 (1997) 131–139

Computer Methods and Programs in Biomedicine

Experiences with the German teleradiology system MEDICUS

U. Engelmann [a,*], A. Schröter [a], U. Baur [a], O. Werner [a], B. Göransson [b], E. Borälv [b], M. Schwab [a], H. Müller [a], M. Bahner [c], H.-P. Meinzer [a]

[a] Division of Medical and Biological Informatics, Deutsches Krebsforschungszentrum, Im Neuenheimer Feld 280, 69120 Heidelberg, Germany

[b] CMD, Center for Human-Computer Studies, Uppsala University, Lägerhyddvägen 18, S-75237 Uppsala, Sweden

[c] Division of Oncological Diagnostics and Therapy, Im Neuenheimer Feld 280, 69120 Heidelberg, Germany

Abstract

This paper introduces 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 German field test at 13 radiology departments in university clinics, small hospitals, private practices and research institutes. More than 30 thousand images have been transmitted using this system during a 9 month period. Realized application scenarios are: in-house communication, image and report delivery to referring hospitals, remote reporting, radiotherapy treatment planning and research cooperation. Experience has shown that the system is easy to use and saves time. It obviates the need for patient transport and reduces film costs. Experiences of individuals while using the system during the field test helped define the functionality of the second generation teleradiology system which is even more flexible and is also available as a commercial product. © 1997 Elsevier Science Ireland Ltd.

Keywords: Teleradiology; PACS; Field test; Data security; Experiences

1. Introduction

MEDICUS-2 was a project of the German Cancer Research Center (Deutsches Krebsforschungszentrum) in Heidelberg, Germany which was funded by DeTeBerkom in Berlin (a subsidiary of German Telekom). It was carried out in cooperation with the Steinbeis Transfer Center for Medical Informatics (Steinbeis-Transferzentrum Medizinische Informatik) in Heidelberg, which is a technology transfer center in this field, and ran from August 1994 until July 1996. The goal of the project was to develop a teleradi-

* Corresponding author. Tel.: +49 6221 422382; fax: +49 6221 422345; e-mail: U.Engelmann@DKFZ-Heidelberg.de

PII S0169-2607(97)00042-4

ology system that allows radiologists to submit images over ISDN (Integrated Services Digital Networks) as well as over a local network and to perform cooperative work on the same image data.

Radiologists and vendors of software and hardware in this field do not always share the same definition of teleradiology. Therefore, it is probably necessary to point out that we are using the definition given by the American College of Radiology in the 'ACR Standard for Teleradiology' (Res. 21-1994) [1]. This resolution includes an initial definition of teleradiology (in addition to goals, qualifications of personnel, equipment guidelines, licensing, credentials, liability, communication, quality control, and quality improvement for teleradiology). Important requirements defined by the resolution specify that images be sent over a network to a different location and that users must be able to view the images simultaneously. Furthermore, DICOM must be used for the exchange and representation of images and image data must be stored in patient databases.

The motivation for the project is seen in the expectation that a teleradiology system can reduce film costs, patient transport and the need of radiologists to travel to other locations. Since remote experts can be consulted for complicated cases, the quality of health care should be improved through faster and better diagnosis. Another plausible benefit is the reduction of costs through sharing such resources as expensive equipment and radiologists (e.g. during night shifts).

2. State of the art: CSCW and teleconference tools

A number of commercial products for computer-supported cooperative work, CSCW, are already on the market. Therefore, it is necessary to determine whether the available products are able to satisfy the special needs of our users.

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

Examining these products revealed 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 [2] or DICOM [3]. They cannot handle 12-bit images and they provide no specific functions for level/window manipulation or the analysis of gray values. Other functions for image analysis and processing are missing as well. Additional drawbacks include their lack of integration into the existing environment of a radiology department (connection with imaging modality, management of patient data and organizational data).

Furthermore, application sharing systems submit a complete image series (up to 30 Mb) over an ISDN line (2 B-channels, 64 kbit/s each) at a speed that is too slow for efficient interactive cooperative sessions.

Non-commercial research systems like KAMEDIN [4] also did not meet our user requirements (e.g. data security concepts) or the requirements of the ACR [1]. Therefore, we decided to develop a new teleradiology system called MEDICUS.

3. Principles of the MEDICUS system

Images from different sources (e.g. digital modalities, video cameras, document scanners) can be imported into MEDICUS. The transfer of the image data from an MR or CT scanner to the MEDICUS workstation is automated as much as possible. Medical personnel can simply invoke the standard export function on the CT or MR console to start the transfer process. The transfer process is realized by using the DICOM protocol whenever possible or TCP/IP and DECnet-based functions in other cases.

The transferred image data are placed in an import file system of the MEDICUS workstation. A demon 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. The header information of the image files is evaluated so that the images with the accompanying alphanumeric information is stored in the imported database. The MEDICUS program organizes the image data by study ID, patient names, image series, image number, etc. Thus, the user views the organized data in a manner that is similar to that employed at his CT/MR console. Users are not confronted with the operating system, cryptic file names or transfer programs.

Image data can be submitted to a different machine with three mouse clicks. These clicks are necessary to identify the study, to select the addressee and to activate the submission. The user can select a subset of images and write a cover letter that will be sent with the images. Image data is collected in folders. Several folders are collected in packets. The packet is sent to the communication partner and the sender controls the rights on the submitted image data. Possible restrictions include: only viewable in a teleconference with the sender, not exportable, not printable, automatic removal after the teleconference. The packet is encrypted with a public key encryption system PGP [8] and is signed with the digital signature of the sender. A checksum of the data is calculated. This protects data integrity and assures authentication of the sender and privacy for the receiver.

Data are internally buffered in a transfer database where they await submission at a date and time defined by the user. The transfer process copies the data into a shared database at the target machine. After the remote machine has acknowledged the transfer, data are also stored locally in a shared database. The data transfer is usually conducted off-line, because a typical data set contains several megabytes of information. This may require hours of transmission time on an ISDN line. Without employing compression, one CT image (512 by 512 pixels, 2 bytes/pixel) can be transferred over an ISDN line with two B-Channels (64 kbit/s) in about 33 s. A typical image series has 30 to 60 images and may sometimes consist of more than 240 images, as in the case of MR mammography.

A teleconference is initiated by a telephone call. The conference partners invoke the application (Fig. 1) and one of the partners selects the other to establish the connection. The system automatically establishes the ISDN connection. Both partners see the identical shared data that were transmitted between them. Both parties 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 analyze the gray values and regions of interest (area, density values). A part of the image can be magnified. The viewable gray value range can be changed in a manner 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 so that both partners see exactly the same information 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 that are in turn based on global design decisions already in effect before system design and implementation was started:

The teleradiology system is based on the UNIX operating system. The reason for this is that the MEDICUS system is mainly a communication system and the best connectivity features today are found on UNIX systems.

The MEDICUS communication protocol is based on a dedicated message passing concept using TCP/IP and sockets [9]. 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.

ISDN is the physical target network. A standard S_0 telephone plug is used to communicate with the basic rate interface (BRI) of the com-

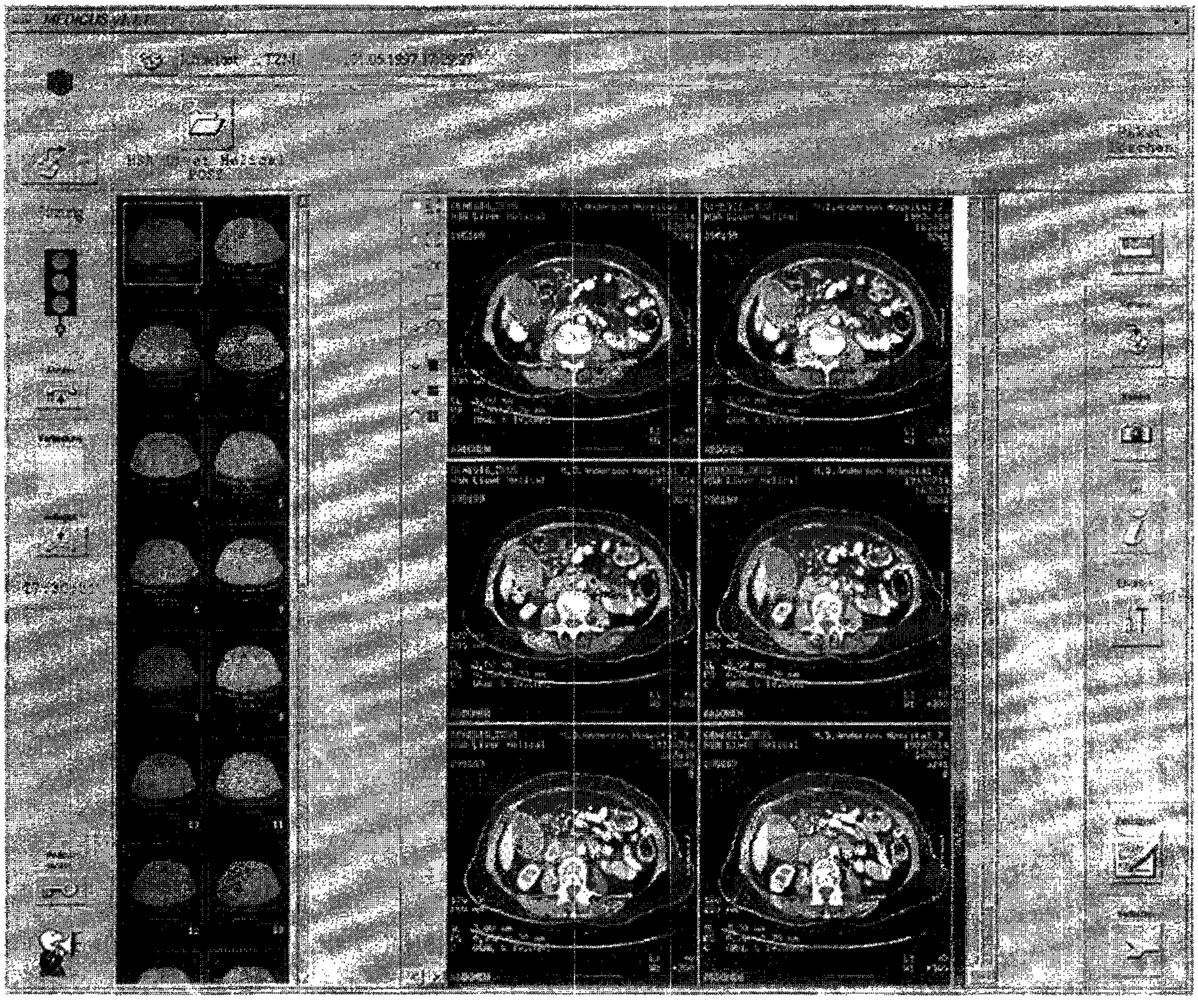

Fig. 1. Screen dump of the MEDICUS program.

puter. 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). TCP/IP is used in conjunction with PPP (point to point protocol) on the ISDN line.

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 [7]. 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 the operating system. He has no contact with the 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 on the system.

Digital imaging modalities are directly connected to the MEDICUS system. The DICOM protocol (C-Store) is used to receive the data from the modalities. Dedicated connections have been realized for non-DICOM compliant machines. The image transfer works in the background without user interaction. MEDICUS supports the image communication and file standards, ACR/NEMA [2] and DICOM [3]. Since proprietary formats exist in the field, processing such formats cannot be avoided (e.g. SOMATOM, MAGNETOM).

Other image sources are supported. Images can be captured from various video sources, e.g. cameras, video recorders, ultrasound scanners.

Off-line data transfer: since large data sets need to be processed, it is not feasible to conduct the data transfer during cooperative sessions. Therefore, the data transfer is performed before the session (during off-peak hours).

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 documentation. The data can be sent to the communication partner during the teleconference. Optionally, the image can be compressed using lossy JPEG compression. Since radiological users did not want it, live video is not supported.

All data in the system are stored in databases that have been realized with ndbm, a portable shareware database standard.

Data protection and security: since image data contain patient information, data protection issues are relevant to the application of this teleradiology system. A security concept has been established and implemented for MEDICUS. Technical, educational, organizational and software requirements have been taken into account for the security concept [5]. The guideline used was the Information Technology Security Evaluation Manual of the Commission of the European Union [6]. Local data are encrypted with a symmetric encryption algorithm and shared data are encrypted with the public key encryption system PGP[8]. Digital signatures and checksum methods are used to protect integrity and authentication.

Portability: the system is portable onto different UNIX hardware/software systems. Development platforms are the Silicon Graphics Indy and O2 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.

5. Experiences

5.1. Results of a field test

The project began with 15 medical partners. Two partners left the consortium during the project, as it proved too expensive to connect their CT scanners with the MEDICUS workstation (over US$ 35 000 installation costs each). The remaining 13 partners came from a private radiological practice, small hospitals, university clinics and a research institution. Ten partners are located in the Heidelberg/Mannheim area in southwestern Germany. Two partners are in Essen in the northwest and one partner is in Nürnberg in the southeast. The installation of the MEDICUS system started in December 1995. Installation was completed at all sites in April 1996. A system evaluation then started and is still on going. All users began with a learning and test phase for several weeks. Five institutions are using the system in their daily clinical routine. The number of program invocations has been logged since April 1996. A more sophisticated logging system was installed in June 1996. Different evaluations have been performed on these data.

5.2. Accounting numbers

The program has been used 3131 times from June 1996 to February 1997 (Table 1). More than 31 000 images from CT and MRI have been im-

Table 1
Accounting numbers from June 1996 to February 1997

Program invocations	3131
Partners	13
Imported images	31 166
Transmitted images	26 457
Transmitted studies	623
Number of teleconferences (by ten partners)	170
Typical duration of a teleconference (min)	5

ported to the MEDICUS system. 26457 Images in 623 packets have been sent to other medical partners via ISDN. Usually, one packet contains one study with several series of images.

The partners conducted 170 teleconferences which typically lasted 5 min each. All teleconferences were shorter than 10 min. The mean conference preparation time was less than 0.5 min. Preparation time increased to about 2 min when an accompanying cover letter had to be written.

5.3. *Application scenarios*

Various institutions are using the system in very different scenarios. One partner (University Clinic Mannheim) has two systems in its clinic and is using it on a local Ethernet for in-house communication. It is not necessary to explicitly transmit the image data from one system to the other since both systems share the same database. In such a context, the MEDICUS system acts more like a viewing station that has teleconference capabilities.

Another partner (the Radiology Department at the German Cancer Research Center) is using MEDICUS to deliver images and a short diagnosis to the referring physicians at two smaller hospitals (Ev. Krankenhaus Salem and Krankenhaus Speyerers Hof). The findings are discussed by the radiologists at the cancer center and the clinicians (internal medicine or urology) in teleconferences. These same radiologists then send images to the Department of Gynecological Radiology at the University Hospital in Heidelberg. CT images are further processed by a radiation therapy planning system.

One small hospital (Ev. Lutherkrankenhaus, Essen) is sending images to the Radiology Department of a clinic (Klinikum Niederberg, Velbert) where the images are analyzed. The teleconference capability is not often used for this purpose.

Another important application scenario is the transmission of images for scientific purposes. The image processing group at the German Cancer Research Center receives images from several (radiological) partners for basic research in image processing or clinical trials with new image processing methods. The results are sent back to the physicians for further discussion.

Yet another possible application, asking another radiologist for his/her second opinion, was used only occasionally. It is our experience that there is currently no major role for this in a teleradiology system. The still unresolved problem of receiving reimbursement of expenses from health insurance companies is an important reason for this.

An important result revealed by the field test was that the participating medical partners improved existing and already very well established cooperations. Very few new cooperations were established for the routine use of teleradiology. This may be due to the overall limited number of connected sites.

5.4. *Technical experiences*

We experienced the following when the teleradiology network was built: it was initially expected that all imaging modalities would be connected to the MEDICUS system using the DICOM protocol and image file standard. But at that time, not one of our radiological partners had a device which supported this standard. Instead, we had to connect each of the ten devices 'by hand' in close cooperation with the vendors and their field technicians. The connections are based on the DECnet and TCP/IP protocols. NFS, FTP and remote copy functions had to be used to realize the image transfer. It was observed that the openness and cooperation of the vendors was inversely proportional to their share of the (German) market. ACR/NEMA 1.0 and 2.0 were the best available standards. For nearly every machine, we had to adapt the image import function for vendor or machine-dependent exceptions.

Using UNIX workstations has not been a disadvantage in the clinical environment. Indy workstations (Silicon Graphics) have been used as the standard platform since they come with all the requisite hardware options (ISDN, video, audio, frame grabber). The machines can be switched on and off like a PC. They have an easy-to-use graphical desktop interface which is combined with the power and security of a UNIX system. Existing personal computers can also be used under the Linux operating system.

No major problems have been encountered with the ISDN telephone lines of German Telekom. Only a single connection was out of order for one day after a heavy thunderstorm destroyed some switching equipment. Two different ISDN protocols are simultaneously being used (1TR6 and Euro-ISDN or DSS-1). Protocol conversion occurs automatically.

5.5. Clinical experiences

Thirteen application sites are presently using the MEDICUS system. All sorts of different teleradiology scenarios are covered. The Division of Oncological Diagnostics and Therapy at the German Cancer Research Center has been routinely using the MEDICUS system since December 1995 for teleradiology communication with two regional hospitals (Ev. Krankenhaus Salem and Krankenhaus Speyerers Hof) and the Department of Gynecological Radiology at University Hospital in Heidelberg. In this setting, we gained experience in using teleradiology for routine consultations between radiologists and clinicians, for expert consultations, for scientific cooperation and for data transfer to be used in radiotherapy treatment planning.

The MEDICUS system is a tool providing a very high degree of functionality. Such functionality depends on the necessary data import which employs the existing copying functions of the digital imaging modalities and automated procedures that occur in the background. Data importation can usually be conducted by an engineer. The transfer of image data via ISDN as a basis for teleradiology conferences requires only a small number of mouse clicks and can be readily completed by even the most inexperienced users.

The MEDICUS system is used very easily during teleconferences. System speed is good. Even new users who are unfamiliar with computers can be easily guided through the teleconference session by explanations provided by telephone. The system offers the basic image workstation procedures like level/window manipulations or densitometry. All functions are readily accessible. Data privacy is assured. This is very important for the transfer of patient-related data and leads to improved acceptance by clinicians and patients. The introduction of the teleradiology system MEDICUS can lead to reduced costs of copying film material which is often necessary to provide the treating physicians with relevant information. In our own experience, this cost reduction exceeds the additional costs for using the ISDN lines. Additionally, information flow is improved. This results in an accelerated availability of information and subsequent improved treatment of patients. Further cost reductions may result from this. Larger studies are needed to better evaluate this aspect.

6. The next generation of teleradiology

Systems that do not fulfill the ACR requirements are called generation zero by the authors. Specifically, such systems do not allow cooperative teleconferences and have no patient database or no DICOM interfaces. MEDICUS can be regarded as a first generation teleradiology system. Based on the experiences of first generation users, it is possible to specify a list of requirements for the next (second) generation. Such requirements have been collected from different sources; the most important ones originate from users participating in the MEDICUS field test.

Additional system features of the second generation can be divided into several groups [10]:

- General architecture: the future system should be a radiological viewing station that is connected to all imaging modalities (including laser imagers and archives) via the DICOM protocol. It is portable to different hardware and software platforms (including Windows NT). The teleradiology feature is one of several 'add-ons'.
- Viewing functionality: the system can be used for reporting and (re-)viewing images. All image manipulations possible on a professional image workstation are available. Small matrix images such as CT or MRI are supported as are large matrix images such as digitized films or computed radiographs. The user has a choice of different monitors (color, gray scale, different size, resolution, luminance). The workstation can have more than one monitor.

- Extensibility: the basic system can be extended by the users with plug-ins. Developer kits are available. Plug-ins will be developed for advanced image analysis and 3-D visualizations.
- Patient database: the SQL and ODBC standards are used to store and manage the local patient and image data. Access to WWW databases is also possible.

By mid 1996, the Steinbeis Transfer Center for Medical Informatics in Heidelberg, Germany, in cooperation with the German Cancer Research Center, began developing a system, as described above. 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.

7. Future challenges

Interfaces to the radiology information system (RIS) and the hospital information system (HIS) are necessary. Several companies are exploring different standards such as DICOM or HL7 or proprietary solutions depending on the systems in the existing clinical environments. An international (accepted) standard is also needed for generic interfaces between HIS/RIS/PACS and teleradiology.

Future teleradiology systems should permit communication between radiological workstations from different vendors. This demands more conceptual work as systems with different functions and objects on the screen have to be synchronized. It will take some time until an accepted international standard will be available.

The reimbursement for costs associated with a 'second opinion' or a remote diagnosis must become possible in the future.

Teleradiology will also influence certain aspects of the radiological profession.

8. Summary

A teleradiology system, MEDICUS, based on the definitions and requirements of the American College of Radiology and the needs of medical end users has been developed. The system has been in clinical use for more than nine months at thirteen medical institutions and more than 30 000 images have been processed. The system is a valuable and capable tool with a dedicated teleradiology functionality. The existing security concept provides the bare minimum required for any further successful use of teleradiology systems in the future. MEDICUS results in an improved information flow in clinical settings and makes an accelerated and more effective treatment of patients possible. Cost reductions are obvious, but further research must be performed in this field.

Although MEDICUS is a successful project, it is still possible to improve the system. Some important features of a second generation system have been defined based on the results of the MEDICUS field test. The Steinbeis Transfer Center for Medical Informatics in Heidelberg is currently developing (and re-implementing) such a commercial second generation teleradiology system called CHILI.

Acknowledgements

We would like to thank all the medical partners participating in the project for their support during system analysis and program use as well as their constructive comments on the system itself.

References

[1] American College of Radiology, ACR Standard for Teleradiology, Res. 21-1994, available on the WWW at http://www.acr.org/standards.new/teleradiology_standard.html.

[2] American College of Radiology, National Electrical Manufacturers Association, ACR/NEMA Digital Imaging and Communications Standard, Version 2.0, in: ACR/NEMA Standards Publication No. 300-1988. Washington, DC, 1988.

[3] American College of Radiology, National Electrical Manufacturers Association, Digital Imaging and Communications in Medicine (DICOM), Version 3.0, in: ACR/NEMA Standards Publication No. PS3. ACR/NEMA Committee, Working Group.

[4] H. Handels, Ch. Busch, J. Encarnacao, et al., KAMEDIN: A telemedicine system for computer sup-

ported cooperative work and remote image analysis in radiology, Comput. Methods Program Biomed. 52 (1997) 175–183.

[5] H.J. Baur, U. Engelmann, F. Saurbier, A. Schröter, U. Baur, H.P. Meinzer, How to deal with security and privacy issues in teleradiology, Comput. Methods Programs Biomed. 53 (1) (1997) 1–8.

[6] Information Technology Security Evaluation Manual, ITSEM, Brussels and Luxembourg 1994, DGXIII, ISBN 92-826-7087-2.

[7] E. Olsson, The HELIOS Style Guide, available on the WWW at http://www.cmd.uu.se/papers/sg.html

[8] S. Garfinkel, PGP: Pretty Good Privacy, O'Reilly and Associates, Cambridge, 1995.

[9] R. Stevens, Advanced Programming in the UNIX Environment, Addison-Wesley, Reading, MA, 1992.

[10] U. Engelmann, A. Schröter, U. Baur, et al.,Second Generation Teleradiology CAR '97: Computer Assisted Radiology, 11th Int. Symp. and Exhibition, Berlin, Elsevier, Amsterdam, 1997, (in press).