Distance learning in mammographic digital image processing

L COSTARIDOU, PhD, G PANAYIOTAKIS, PhD, P SAKELLAROPOULOS, MSc, D CAVOURAS, PhD and J DIMOPOULOS, MD, PhD

Department of Medical Physics, School of Medicine, University of Patras, Department of Medical Instrumentation Technology, TEI Athens, and Department of Radiology, School of Medicine, University of Patras, Greece

Abstract. The potential of interactive multimedia and Internet technologies is investigated with respect to the implementation of a distance learning system in medical imaging. The system is built according to a client-server architecture, based on the Internet infrastructure, composed of server nodes conceptually modelled as World Wide Web (WWW) sites. Sites are implemented by integration and customization of available components. The system evolves around network-delivered interactive multimedia courses and network-based tutoring, which constitute its main learning features. This potential has been demonstrated by means of an implemented system, validated with digital image processing content, specifically image enhancement. Image enhancement methods are theoretically described and applied on mammograms. Emphasis is given in the interactive presentation of the effects of algorithm parameters on images. The system end-user access depends on available bandwidth, so high speed access can be achieved via LAN or local ISDN connections.

Introduction

Medical digital image processing methods are characterized by rapid evolution and poor representation in clinical routine [1]. Thus the need for training of medical imaging personnel in such methods, with emphasis on their applicability to images resulting from various modalities, is increasing.

To serve training, the use of computers and information technology has been utilized [2]. Specifically, the advantages of computer based learning methods have been exploited in the design and development of stand-alone learning systems in medical imaging [3–9]. Recently, the availability of telematics technology has introduced an evolution of these systems to distance learning systems. These systems introduce new learning dimensions, such as support of learning through computer mediated learner–tutor communication [10, 11].

Specifically, distance learning in medical imaging may benefit from fast multimedia internetworking technologies, since its information domain is characterized by multimodality and volume. These benefits are attributed to: cost by resource and expertise sharing, quality of teaching material and efficiency of access. Several systems have been introduced in the last few years which attempt to take advantage of these benefits [12–15].

In this paper, distance learning services are presented for digital image processing methods and their application in mammography. These services are part of an integrated system, the PRONET, which is aimed at demonstrating the potential of interactive multimedia and Internet technologies to support training. The intended audience of the distance learning services are medical physicists, biomedical engineers and to some extent radiologists. Some of the computing terminology used in the paper is presented in Appendix 1.

Methods and materials

System functionality

The main features of the presented distance learning system are: (a) network-delivered interactive multimedia courses and (b) network-based tutoring, relying on on-line asynchronous computer communications. The first feature provides independent learning under user control, while the second provides guided learning by tutors, relative to questions raised with respect to the content of
the courses. To implement these features a client-server architecture is used, utilizing the World Wide Web (WWW) infrastructure [16–18]. A server is conceptually modelled as a WWW site integrating interactive multimedia and tutoring services. To offer improved access to the services at European level, a computer network of three servers located in Spain, The Netherlands and Greece is implemented.

System architecture

The PRONET system architecture is based on an integration and customization approach [19, 20] of market available components. These components have been selected with respect to competitiveness and compatibility with WWW server and browser environments. The main benefits of this approach are reduced development time by reducing code development from scratch, increased system modularity, which allows system modifications to future needs and compliance with trends and existing or emerging standards [21].

Specifically, the network level architecture is based on the transmission control protocol/Internet protocol (TCP/IP), which offers compatibility of services and worldwide access. Thus, the performance of the PRONET services is dependent on and to some extent limited by Internet transfer rates, so that mechanisms have to be provided in order to accomplish a high or satisfactory level of services (course downloading and bandwidth for communication services). In addition, local area network (LAN) and local integrated services digital network (ISDN) high speed access modes can be used to achieve increased bandwidth and simultaneously executed services.

The operating system for the server environment is MS-Windows NT 4.0 (Microsoft Corporation, Redmond, Washington).

The WWW site (server) is implemented using the Netscape Enterprise Server 3.0 (Netscape Communications Ltd, Middlesex, UK). Besides integrating training and tutoring services, associated with interactive multimedia courses and communication facilities, the site provides additional course and tutoring management capabilities, implemented as a relational database, accessed by navigation or key-search mechanisms (Sybase SQL Anywhere, Sybase, London, UK). Examples of management capabilities are: user registration, attendance, user profiles and statistics, testing, assignment of tutors and tests to courses.

Client configuration

A personal computer (PC) with an Internet connection is required in order to access the system. The minimum configuration consists of a PC equipped with a 486 processor running at 66 MHz, 16 MB of RAM, a sound card (preferably full-duplex) and a 800 × 600 pixel, 24-bit colour display.

Internet connection can be achieved through organizational network cabling or through a modem connected to an Internet provider. An Ethernet network interface card or a modem with at least 14400 bits s\(^{-1}\) transfer rate capacity are required respectively.

Software requirements include: MS-Windows 3.1 or preferably MS-Windows 95, Internet (TCP/IP) communication software and dial-up networking software for modem connections, Netscape Communicator 4.0 WWW browser with the Macromedia Shockwave plug-in installed (this can be downloaded from the PRONET site). To improve the access of the multimedia courses, especially in case of slow connection, the user should increase the Netscape disk cache size (e.g. 50 MB).

Network-delivered interactive multimedia courses

A course is a set of didactic units and chapters organised in a hierarchical manner (Figure 1) in a dynamic book, which allows elements such as text, images, clinical images, graphics, animation, sound and buttons to be combined. Each unit is associated with an objective and means of assessment of the achievement of this objective (tests, questions). Screen content was developed according to generic descriptions, templates, which specify the sequence relations of a screen's mediatic content to the hierarchical structure of a course. Clinical images are digitized (ScanJet II cx/T, Hewlett Packard, Berkshire, UK) with 8 bits/pixel bit depth, 300 dpi spatial resolution. Regions of interest (ROI) have been extracted and subsampled resulting in fixed image size of 256 × 256, 66 KBytes. Images have been off-line processed using original scripts of MATLAB v4.2 (Mathworks Inc., Natick, Massachusetts, USA), original C++ code and public-domain routines (Wavelab Toolkit and Wave2). It is noted that these digitization specifications are dictated by the minimum client display specifications as well as by the generic character of the development tools used. Although, these

![Figure 1. The hierarchical structure of a multimedia course.](image-url)
specifications limit clinical image quality, they are sufficient for educational purposes. Courses are initially implemented in the Macromedia Director 5.0 authoring environment (Macromedia Europe, Berkshire, UK), which supports the Netscape browser, by means of an available plug-in. Each Macromedia Director file corresponding to a chapter is converted to a compressed file format, which can be downloaded and played at the client environment upon user request.

**Tutoring**

Tutoring is based on a point-to-point connection (tutoring session) between tutor and trainee. The session is off-line scheduled on the basis of available tutors and e-mail sent from trainee to tutor. Tutoring relies on collaborative: (i) browsing of multimedia content initiated and controlled by the tutor and (ii) white board facilities (i.e., pointing, drawing, annotation). Collaborative browsing refers to the synchronization of the display between tutor and user, while white boarding refers to common editing of a display. This is further supported by human communication through video, audio and text conversation (chatting), the latter consuming few network and computer resources (Netscape Communicator 4.0, Netscape Communications Ltd, Middlesex, UK). Data collaboration is supported by means of transfer of data files during a session. The content of a tutoring session (annotated screens and discussion content) can be saved for review.

**Results**

The results of this study refer to the implementation of the distance learning system. This system is validated with digital image processing content.

**The system**

The distance learning system is implemented as a network of WWW sites. Each site integrates network delivered interactive multimedia courses, network-based tutoring as well as additional course and tutoring management functions (Figure 2).

The system user interface enables direct access (browsing) via navigation buttons. Upon personal

![Figure 2](image_url)

**Figure 2.** The distance learning services of the implemented system, appearing as a menu of three selections (in the background window) with activated multimedia course table of content (in the foreground window), as a result of a training course selection. Additional buttons provide access to other site information content.
Medical image enhancement content is organized according to theoretical and case-oriented approaches, in respective units. The theoretical units are targeted to concept definition and algorithm description material. For the latter, an intermediate level of presentation is adopted, focusing on the major logical steps of an algorithm, which are presented as a causal interaction map [24] (Figure 3). In describing the algorithms, emphasis is given in the presentation of the effects of key input parameters to processed images, which is offered as an additional functionality enriching the interactive character of the respective units (Figure 4). In the case-oriented units (Figure 5), the algorithms theoretically presented, are applied on clinical data. Their effect is assessed by means of comments, provided by radiologists, on image features of diagnostic relevance (Figure 6).

The contrast enhancement methods covered are negative imaging, contrast stretching, histogram equalization, unsharp masking, high frequency emphasis, Gabor–Sobel edge enhancement,
wavelet denoising and linear/non-linear/hyperbolic function enhancement [23, 25–28].

Tutoring

Network-based tutoring relies on collaborative browsing of multimedia course content and white board editing facilities, complemented by human communication (video, audio and chatting). An instance of the collaborative learning process is shown in Figure 7. The learning process of the system relies on autonomous computer based learning (CBL), by network-delivered interactive multimedia courses, selected from available catalogues (curriculum). These are complemented by: (a) (off-line) scheduling/planning of network-based tutoring, by means of assignment of available tutors to courses, to enhance the system’s learning potential, and (b) self-evaluation mechanisms based on multiple choice questions (MCQ), which are attached by tutors to courses.

Discussion

The major benefit of the presented system is widespread access to educational resources and professional expertise, due to the utilization of the WWW infrastructure. Another benefit is the easy update and enrichment of course content, as a direct consequence of its digital nature. However, course update is not available to non-programmer course contributors (authors), since it requires the use of a scripting language (Lingo scripting language, Macromedia Director 5.0, Macromedia Europe, Berkshire, UK). This could be achieved by input mechanisms, which invoke course templates [29] equipped with codes required to
An instance of a tutoring session. In the left window, collaboratively browsed multimedia content is displayed, which corresponds to selected multimedia course screen (Figure 3) with additional annotation (i.e., tutor and trainee pointers, additional text, and selected screen areas). The discussion between tutor and trainee is displayed in the right window.

implement the structure and behaviour of a course unit, chapter or screen.

With respect to the benefit offered by the tutoring services, there are some limitations introduced by the options of the network communication tool (Netscape Communicator 4.0, Netscape Communications Ltd, Middlesex, UK). Specifically, the presented collaborative browsing scenario does not fully utilize the WWW aspect of collaborative browsing, since the presented multimedia courses are not distributed. Furthermore, in future system upgrades, the learning dimensions of the tutoring scenario could be strengthened by capabilities, such as collaborative authoring and browsing of course structure, to provide more context in learning. Thus, tutoring services could become a collaborative tool, according to current trends in distance learning systems [30].

The presented system has not been formally evaluated. However, it has been initially exposed to internal users (radiologists of the University Hospital of Patras and post-graduate students of the Medical Physics Department of the University of Patras) with a positive response. A systematic evaluation will be performed at a European level, following the full-scale implementation and demonstration of the system. The evaluation plan is based on system performance metrics, course content indicators and rating of the effectiveness of the system as a learning tool. System performance metrics considered are: course access time (defined as the average time required by the client browser to download the chapters of the course), real-time tutoring performance (defined as quality and continuity of video, audio and whiteboard). These metrics will be evaluated with respect to client bandwidth Internet connection, distance from the site and client hardware configuration. Course content indicators considered are: completeness and correctness of material, organization of the material and user control provided by the system user interface, quality and relevance of media used. The effectiveness of the system as a learning tool is assessed by MCQ testing scores, indicating knowledge acquired with respect to attended course content. Evaluation data will be collected from user groups by means of questionnaires and interviews.

Finally, an open issue is the optimal utilization of the recognized WWW potential to serve training
in medical digital image processing and medical imaging in general, since development efforts have just started.

**Conclusion**

The potential of combining interactive multimedia and Internet technologies to support training in medical imaging is investigated. This potential has been demonstrated, by means of a system integrating network-delivered interactive multimedia courses and network-based tutoring. A paradigm pertaining to mammographic digital image processing content was used, in an attempt to validate this system.

It is felt that learning services based on telematics, and especially WWW, provide powerful new means of improved access, and sharing of learning resources, as well as sharing of expertise through communication and collaboration, as promising supplements in learning.

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**References**


Appendix

Glossary of computing terminology.

Browser: Client software used to display WWW documents.

Client: A computer using services or resources provided by a remote computer, called server.

Client-server architecture: An architecture that provides for the splitting of user requests (usually called clients) and a related server function, most commonly across a network.

Downloading: The electronic transfer of information from one computer to another, generally from a server computer to a client computer.

Hypertext transport protocol (HTTP): The protocol used to transfer WWW documents from a server to a client.

Integrated services digital network (ISDN): A set of communication standards that enable a single phone line or optical cable to carry voice, digital network services and video. ISDN is intended eventually to replace the standard telephone system.

Local area network (LAN): A group of personal computers located within a small geographic area (typically owned by a single institution) linked together in order to share programs, data and peripherals.

Protocol: A series of rules that determine how the data will flow on a communication standard.

Server: A computer providing a particular kind of service to client computers. A server machine might have several different server software programs running on it, providing many different services.

Transmission control protocol/Internet protocol (TCP/IP): It is a combined set of protocols that performs the transfer of data between two computers. TCP monitors and ensures correct transfer of data. IP allows data to travel in packets routed across different networks, then reach their final destination and be reassembled. It is the standard protocol upon which the Internet is based.

World Wide Web (WWW): A hypermedia-based system for accessing Internet documents containing multimedia resources (text, images, sounds, animations, video). It permits to establish hypermedia connections among documents stored on computers called WWW servers.

WWW server: A computer that stores and distributes WWW documents on the Internet. The term can also refer to the software running on the server for this purpose.