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Original Paper

Telemicroscopy by the Internet revisited

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Abstract

This paper reports a fundamentally new concept for internet-based telemicroscopy. By separating a telemicroscopy application into three tasks – microscope control program, external server, and client application – it is possible to establish a telemicroscopy session between two arbitrary end points on the Internet even if both of the end points are secured by firewall (microscope *and* client application). The advantages of such a distributed system, compared with the classical point-to-point systems, are discussed. The telemicroscopy system is combined with a telepathology database, which is capable of automatically recording telemicroscopy sessions, allowing a convenient combination of interactive remote microscopy and store and forward telepathology. In addition to remote primary diagnosis, it is easily possible to discuss difficult cases within dedicated user groups, no matter whether images originate from a telemicroscopy session, or are manually entered into the database. Copyright © 2001 John Wiley & Sons, Ltd.

Keywords: telepathology; telemicroscopy; telemedicine; Internet; distributed systems

Introduction

Since the early years of telepathology in the 1980s with specialized hardware and communication links [1], there has been a tremendous development in general purpose (multimedia-) computing as well as in the availability of network links such as the Internet and Integrated Services Digital Network (ISDN). Today, almost any pathologist's desktop computer is fast enough for telepathology and most offices are equipped with a fast Internet connection. As yet, however, except for a few point-to-point systems for frozen section diagnosis using specialized hardware [1–3], there is no widespread use of telepathology.

Besides intra-operative diagnosis, there is an increasing demand for the usage of telepathology for second opinions or scientific consultations [4]. Ideally, a pathologist should be able to connect his/her microscope to the desktop computer in his/her office and use the hospital's Internet connection to share the microscope with any other pathologist with an internet connection. A concept for telemicroscopy using the Internet and a conventional web browser has recently been introduced [5–7].

However, a fundamental problem in using the Internet as a network link for telemedicine applications is that transmitted data are basically not secure. As a consequence, most hospitals have secured their internal network (Intranet) with so-called firewalls. These firewalls, however, are a major problem for the use of the Internet for telemedicine, as they prohibit a direct connection between two computers located in two different hospitals [8]. Although it is often not explicitly stated, a direct Internet connection is required by most existing telepathology applications.

In the present article we present a new concept for interactive telemedical applications which allows the use of any internet connection, secured by any type of firewall, to share a scientific device such as a microscope between several users over the Internet. To illustrate this concept, we will describe our prototype implementation of such a system; however, the main aim of this paper is to demonstrate how it is possible to deal with secured internet connections as they are present in almost any hospital. The emphasis of this article is therefore clearly on the technical solution for telepathology networks rather than on the diagnostic validity of yet another system. For most pathologists who are trained to make their diagnosis on a real microscope, some time is needed for 'acclimatization' before they are comfortable making diagnoses from digitized images on a computer screen [9].

The complete software referred to in this article and additional technical information is published online at http://ipath.sourceforge.net.

Using the Internet for telemedical applications

If the Internet is to be used for telemedicine, it is necessary to consider the fact that most users of any telemedicine application will be working in a hospital where internet connection is almost always secured by firewalls. A firewall is basically a filter that is located between the hospital's intranet and the open Internet. This filter allows only connections from within the hospital to the outside and only for certain networking protocols (such as HTTP and e-mail). It is therefore not possible to connect directly two computers located at two different hospitals, as each attempt to establish a connection would be blocked by the other's firewall.

To allow any use of the Internet, a firewall must at least tolerate outbound connections to receive web pages. Technically, this means that the hypertext transfer protocol (HTTP) is always open for outbound connections. Other protocols such as File Transfer Protocol (FTP) or Telnet are often closed and inbound connections are almost never tolerated. If a telepathology system is to make use of the Internet as it is present on a typical hospital's Intranet, it must therefore only make use of outbound HTTP connections for data transfer. A simple but practicable example of such a system, using common webcam technology (with image upload over FTP), was recently established in the UK [8].

To implement a telemicroscopy system under such restricted conditions, we separate the telemicroscopy application into three tasks, which are implemented as independent modules: a 'microscope control program', the 'client application', and a 'telepathology server', which is located in the Internet and routes data between the microscope control program and client application for an arbitrary number of telepathology sessions (cf. Figure 1). In the following section, we give a brief overview of these modules as they are implemented in our prototype system.

A way out: distributed system for telemicroscopy

Connecting the microscope: the microscope control program

The microscope control program is an application that on one side physically controls the microscope and captures images from a camera, while on the other it can communicate with the www-server. To discuss a difficult case with a remote expert, a pathologist starts the microscope control program, which has to be installed on his/her computer. After setting illumination and optionally preparing a map image (an overview which is composed of several images at low magnification) the microscope control program registers the microscope with the www-server and waits for instructions from remote clients. If the local or non-specialist pathologist has a motorized microscope, the microscope control program will operate it according to instructions from the clients. Without a motorized microscope, the non-expert must operate the microscope manually. The expert pathologist may instruct the non-expert over a conventional telephone connection. To direct the non-expert to a desired field of view, the expert can use the point and click interface as for a motorized microscope and the non-expert can see the desired position on screen and can change the stage position accordingly. With some experience by the non-expert, it is easily possible to do remote microscopy with a conventional microscope.

In addition to translating instructions from the expert into microscope commands, the microscope control program also sends some sort of 'live image' to the server, from where it is retrieved by the clients. As there is no guaranteed bandwidth on the Internet, we have reduced the transmission rate for the 'live image' to one static image every 1 or 2 s, instead of trying to provide a real-time video. We find that such a low frame rate is enough for most telemicroscopy tasks, except maybe adjusting focus from a distance, but this can be done by the non-expert, who is next to

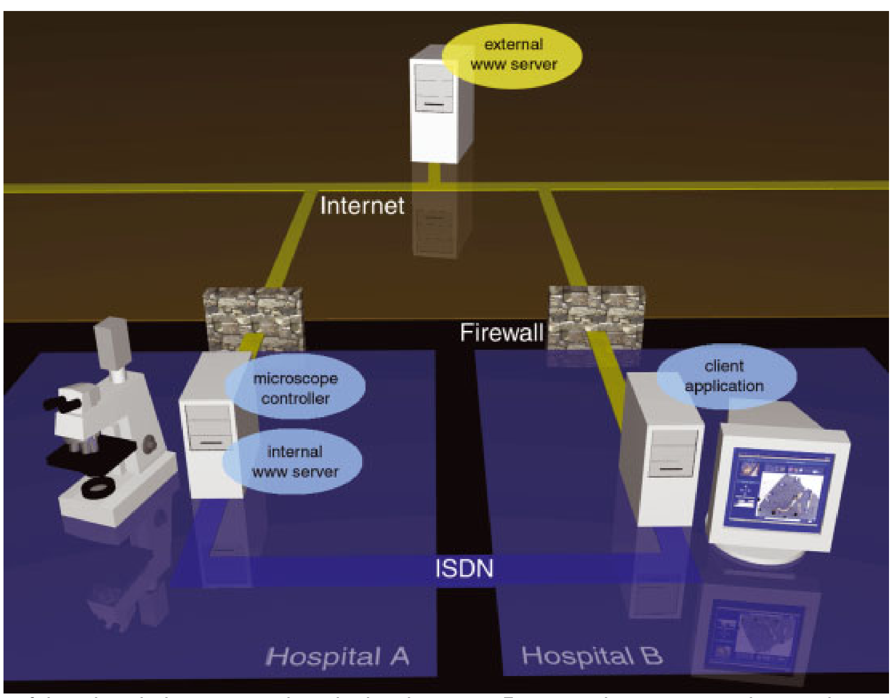

Figure 1. The set-up of the telepathology system described in this paper. For second-opinion consultation, the network connection between the non-expert (hospital A) and the expert (hospital B) is established over the Internet and an external www-server (yellow line). For intra-operative diagnosis, where an open internet connection is not reliable enough, it is possible to run the www-server application on the non-expert's computer that is connected to the microscope. The network link can be established over a 'private' ISDN line

the microscope. As these 'live images' can be heavily compressed, it is possible to provide an almost live feeling for remote microscopy with very conservative bandwidth needs: a single ISDN channel (64 kbit/s) is enough to perform online telemicroscopy. However, if bandwidth and fast computers are available, it should be easily possible to use a compressed video stream instead.

At present, our microscope control program software is running under Microsoft Windows NT/95 and can be used with any 'Video for Windows' (VfW) compatible video input card, and it can optionally control a Zeiss MCU-26 stage controller. Ports to other hardware are in preparation. Support for high-quality frame grabber cards (Matrox Meteor and IC-PCI) is almost completed and support for other microscopes (Olympus and Leica) and OS (Linux) is being worked on. A motorized microscope is not required; a conventional microscope operated by hand, although slightly slower, is sufficient for most tasks.

Using the microscope at a distance: the client web page

The client application is implemented as a JAVA enhanced web page, which has proven to be suitable for a telemicroscopy client [5–7], as it can be used on any computer platform equipped with a conventional web browser such as Netscape Navigator or Internet Explorer. Figure 2 illustrates how the microscope is represented to the remote expert. A small 'live image' (top left, updated regularly according to the present bandwidth) always shows the current view under the microscope. Single high-quality images (true colour VGA) can be captured and are then displayed on the right side. Images are stored and transported in standard JPEG format. The compression rate can be set dynamically, which allows the users to make a reasonable trade-off between speed and image quality. If the magnification is increased or the stage moved, the new position is indicated on the captured image with a rectangle (cf. Figure 2). The microscope can be directed to a new field of interest by clicking at the desired position in the captured image.

As the application can store several captured images, it is always possible for the expert to scroll back to earlier locations and continue the investigation from there. In addition, every session is recorded by the telepathology server, so that it can be reviewed even when the microscope is no longer online, to allow archiving and later discussion of difficult cases (cf. Figure 3).

The telepathology server

As in most cases, due to restrictive firewalls, it is not possible to establish a direct connection between client application and the microscope control program, we introduce an external server to route data between the microscope and clients. Basically, the telepathology server is a web server with support for active web pages (PHP and JAVA) and a collection of CGI scripts for routing data between th emicroscope and client.

If a telemicroscopy session is to be established, the microscope control program first contacts the telepathology server, authenticates itself and sends the state of the microscope (position, magnification, etc.), and then waits for the next command to be executed. If a client requests some action from the microscope, the telepathology server forwards this request to the listening microscope control program, waits for the answer, and distributes the answer (e.g. a captured image) back to the client. Additionally, the current state of the microscope is stored on the server, so that it can be distributed to all clients without calling back every time to the microscope control program.

As a side-effect of such a triangular architecture, there is always a delay compared with a direct point-to-point connection; the distributed set-up takes about 1–3 s more to complete a request than a direct connection. Compared with the advantage of being able to use almost any kind of internet connection on both sides, this is in our opinion a minimal disadvantage.

Besides routing information and providing access control, the telepathology server can additionally record every session into a database, including all images, with their exact position and magnification (cf. Figure 3). This has proven to be very valuable: sessions can be reviewed and discussed at any time without accessing the microscope; images that have been important for a diagnosis can be downloaded and stored along with other patient information after the interactive session is finished (from all involved partners); and cases of special interest can be published on the telepathology server to a general audience by one click of the mouse.

As no internet server can be fully secured, it should again be stressed here that any data that could be used to identify patients should not be stored on the Internet. If sensitive data are needed along with the images, a simple but reliable solution is the use of a different, secure transport medium, such as spoken language over the telephone or encrypted e-mail (encrypted with PGP [10]).

Discussion

We have shown how to design a telepathology system that uses the Internet as a network link, but is not limited in its use by the restrictive firewalls present in most hospitals. The distributed approach to accomplish this task has many more advantages, discussed below. Lack of inter-operability has been identified as a major drawback of existing telepathology systems [11]. One way of overcoming this problem, an open standard, is almost implicit in a distributed system.

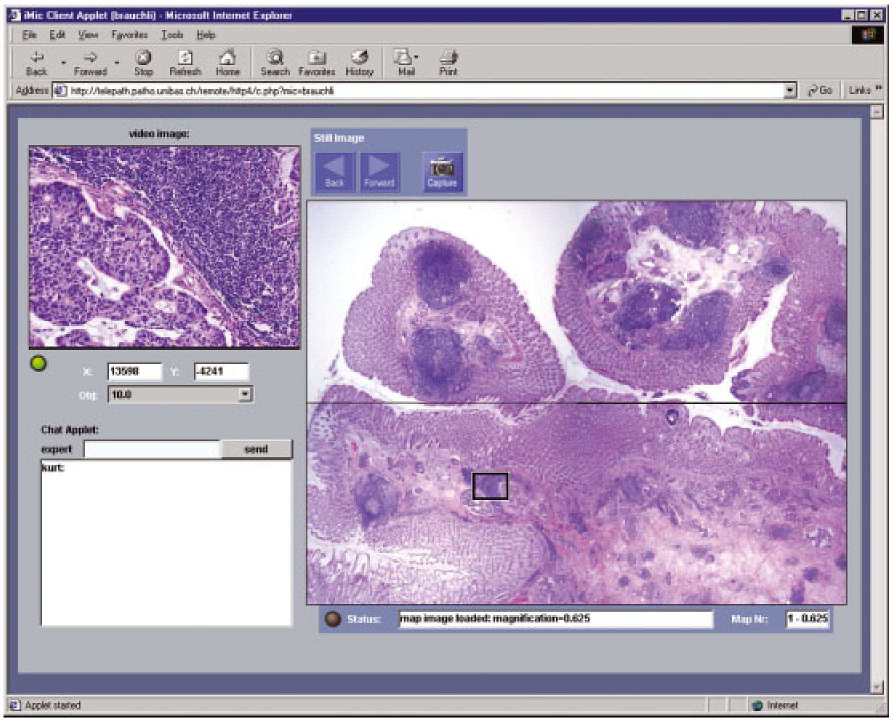

Figure 2. The client application is implemented as a JAVA enhanced web page, which can be used with a conventional web browser. The 'live' video image in the top left corner always shows the actual view from the microscope, automatically updated every 1–2 s. On the right, the last captured image is displayed. With a motorized microscope, the actual position of the live image is always outlined by the black rectangle. With a conventional microscope, the rectangle can be used by the expert to direct the manual operation of the microscope

An open standard

The distribution of process clearly separates the telepathology application into several distinct modules. Provided that the interfaces between these modules are standardized and published, single modules can be implemented or adapted to specific hardware independently from the rest of the system. Improvements to

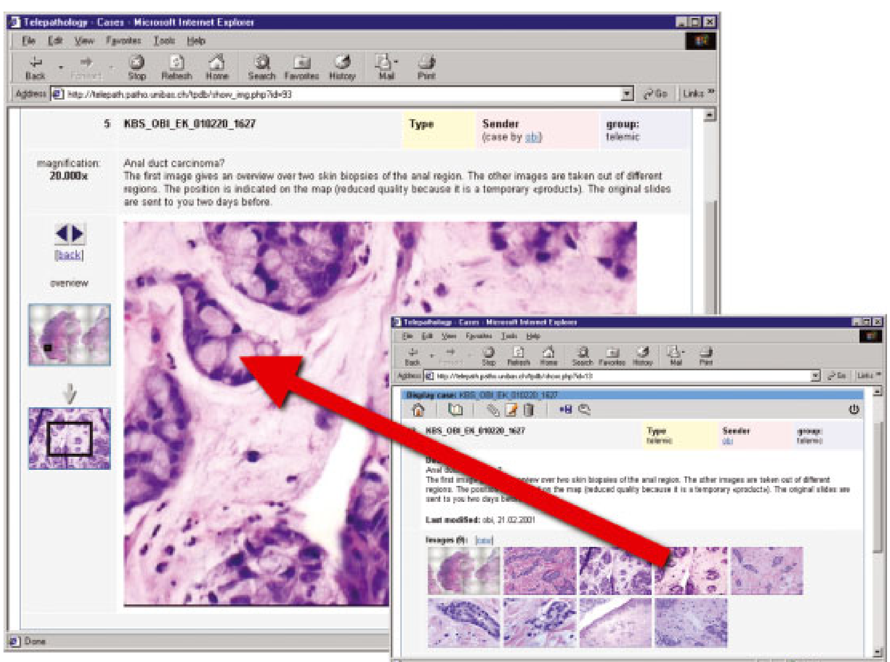

Figure 3. Every telepathology session can be recorded by the www-server, including all captured images with their exact position and magnification. Hence, the complete session can be reviewed or re-discussed at any time without access to the microscope. The real slide must be put back under a microscope only if other areas of the slide are required. In this case, the database will record further images along with those already existing

the server, database or client applets are immediately available to every expert who is using a connection via the server, while the hardware-specific microscope control programs do not need any change at all.

Additionally, the development of new components is no longer restricted to a single vendor or any central authority. At present, development on the telepathology server software will be continued as an academic project with additional partners. The emerging software will be released under the existing open source licence. On the other hand, it would be easy to imagine that microscope vendors could develop and support commercial versions of the hardware-specific microscope control programs.

As an example of such an open standard, we have published the complete communication interfaces of our prototype system online (see below).

Use for frozen section diagnosis

While a range of commercial applications exist especially for frozen section diagnosis, it is perfectly possible to use such a distributed, open system, provided some attention is paid to security and reliability. For example, the telepathology server module can be installed on the same computer as the microscope control program, or anywhere within a hospital's Intranet. Network connection to the expert is established over the Intranet (in-house diagnosis) or over ISDN, so bandwidth need and reliability can be guaranteed, as well as privacy of exchanged data (cf. blue route in Figure 1). By dynamically adapting compression and the transmission rate of images, the system described is functional under very limited bandwidth conditions (64 kbit/s). If external help is needed, the same microscope can be additionally connected to an external telepathology server over the Internet and thus an expert can be consulted immediately.

A small pilot study on routine material demonstrated the same diagnostic performance as desired in routine frozen section diagnosis; neither false-positive nor false-negative tumour diagnoses and a deferral rate below 10% [12]. Compared with a commercial telemicroscopy system, connected by three multiplexed ISDN lines with a robotic microscope, which was used for remote frozen section diagnosis on the same cases, the median time needed was 8 min versus 6 min for telemicroscopy via the Internet versus the commercial system, respectively. It was found that a surgical pathologist does not need special training in the use of such a system, if already familiar with usual desktop PCs.

Combining dynamic telemicroscopy with 'store and forward' consultation

Besides online telemicroscopy, discussion of difficult cases in dedicated user groups is a very important application of telepathology [4]. The distributed system described above allows a very convenient combination of interactive telemicroscopy and 'store and forward' consultations in the very same application. While all telemicroscopy sessions are automatically recorded to the database, there is also the possibility to enter images manually. The advantage of such a flexible solution can be illustrated with some examples. Firstly, images from different sources, such as a gross specimen or even radiology, can be stored along with the images from an online consultation. Secondly, a consultation may be started with a set of images provided by the non-expert, but if the expert wants more information and a telemicroscopy session is then conducted, the images captured during that session are stored automatically, along with those provided by the non-expert beforehand. The presentation and handling of the database are always the same, no matter where the images originated.

Future directions

A first improvement planned for the future is to incorporate a range of collaborative tools that will improve the discussion within a user group. The first step, which is almost completed, is a text-based chat function that allows online discussion between more than two partners. There are some additional advantages of chat-based communication over voice telephone: the communication can be easily stored in text form and there are fewer communication problems between partners with different native languages when using a common language (English) in written form, instead of oral communication (R. Weinstein, oral communication). Due to its modular concept, the system can be easily extended with other collaborative tools, such as a shared pointer or a whiteboard.

Additionally, there are plans to make the telepathology server inter-operable with other existing standards such as DICOM, whereby other image sources (CT, MRI) could be used to feed the telepathology database directly.

Conclusion

While in some special fields telepathology has become reasonably accepted by a variety of users, a general, widely accepted framework is not yet in sight. Most existing systems are conceptually targeted to restricted fields of application and are therefore not very useful as general tools to most pathologists. Although the presented solution is only a prototype, we hope that its concepts and the ideas presented in this article demonstrate how a general framework for telepathology that includes a broad field of telepathological applications, from intra-operative frozen section diagnosis to inter-continental second-opinion consultations, can be implemented using technology that is available today. We believe that only an open, modular framework will help to overcome the obstacles that still prevent the more widespread use of telepathology.

The complete software described in this article is freely available as open source software. The software and more detailed information on the project, especially the communications standard implemented, can be found at http://ipath.sourceforge.net

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