

TeleMedMail: free software to facilitate telemedicine in developing countries

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Abstract

Telemedicine offers the potential to alleviate the severe shortage of medical specialists in developing countries. However lack of equipment and poor network connections usually rule out video-conferencing systems. This paper describes a software application to facilitate store-and-forward telemedicine by email of images from digital cameras. TeleMedMail is written in Java and allows structured text entry, image processing, image and data compression, and data encryption. The design, implementation, and initial evaluation are described.

Keywords:

Telemedicine, digital imaging, free software

Introduction

There is an acute shortage of medical specialists in many developing countries. In sub-Saharan African countries, there are on average less than 10 physicians per 100,000 population¹, and 14 countries do not have a single radiologist². Internet connections are now available in the capitals of all 54 African countries³; however, email is more widely available and more robust over unreliable network connections. One method that has been used successfully to extend the reach of medical specialists is telemedicine⁴. However the traditional approach to telemedicine relies on real-time video interaction between the specialist and the referring physician (and patient). Digital imaging and the availability of ISDN lines have extended the reach of this technology in developed countries, but it remains impractical and uneconomic in remote and resource poor areas. However, medical diagnosis and management can often be achieved with the use of textual descriptions and still images. This "store-and-forward" approach to telemedicine simulates the working patterns of radiologists, pathologists, and those of certain clinical specialties such as dermatology⁵, infectious diseases and ophthalmology⁶. This paper describes a software program called "TeleMedMail" we have developed to simplify the task of organizing and sending clinical data by email.

The widespread availability of two key technologies has recently made store-and-forward telemedicine a practical tool. The first is email systems which allow binary files such as images to be attached and transmitted with the message⁷. Even store-and-forward email systems such as those run by SatelLife are usable for this purpose⁸. Secondly, modern digital still cameras have ample resolution for a variety of clinical images, and are now adequate for digitizing x-ray images in many circumstances. Many physicians in rural Africa are successfully photographing xrays on a viewing box (or well lit window!), and combining them with other clinical images to make email telemedicine referrals⁹.

Although the basic components are in place, there are a number of barriers to the widespread adoption of this approach, particularly in resource-poor areas. While it is fairly straightforward to email a single image to a colleague, organizing and sending multiple images on a regular basis requires good IT skills. Cropping and annotating images must be done in a graphics program, well-organized cases are best sent as documents such as HTML pages, requiring familiarity with HTML editors, and transmission is simplified if the files are zipped into an archive before attachment to the email. There is no security to ensure patient confidentiality with standard email, and no confirmation that the specialist has received the case. Standard methods of compressing image files (GIF and JPEG) are not ideal for all medical images, particularly x-rays and ultrasound. In addition, some type of viewing software is necessary on the receiving computer. While small images may be effectively viewed in a Web browser, larger and more detailed images suitable for reproducing x-rays, require zoom and scrolling functions, and preferably controls for brightness and contrast.

Specialist software to simplify this process tends to be complex, uses proprietary standards, requires good quality networks and is generally too expensive for developing countries. We built TeleMedMail with the Java programming language, and using the Open Source/Free Software approach¹⁰ to ensure the widest availability for this tool.

Technical Requirements and Methods

Image acquisition

High-quality image acquisition is essential for effective telemedicine. Traditional telemedicine systems use a number of specialized imaging attachments to maximize quality of imaging and accessibility to localized areas of the body. As well as being expensive, these devices may not interface easily to routine computer systems. However, digital still cameras intended for consumer or professional use have increased dramatically in resolution and quality of the last five years. Experiments performed in the mid Nineties showed that such cameras could be useful in dermatology and other areas of clinical imaging, and recently there have been a number of small projects using such cameras to digitize x-ray images^{11, 12}. These cameras generally incorporate a zoom lens, built-in flash, and often macro capabilities. Data can be transferred to PC or Macintosh computers by a variety of methods including serial or USB cables, flash memory cards, or, for lower resolution images, floppy disks. Images are generally stored in JPEG format at varying levels of compression but higher end systems may offer the option of storing uncompressed TIFF images. For preformed images such as radiographs or documents, a flatbed scanner can provide high-quality digitization at a reasonable price. However scanners for imaging large size transparencies such as chest xrays are currently very expensive, making it cheaper and more flexible to use a digital camera. An additional benefit of such cameras is their small size and robust construction, allowing use in a variety of clinical situations. This also simplifies transport to remote areas and protection from damage or theft. Use of cameras to digitize x-rays is a new approach that is slowly gaining ground in remote sites as varied as emergency departments in the US¹¹, British Army bases in Bosnia¹³, and sites in South Africa⁹.

Image processing and compression

Once images are stored on the computer, they need to be cropped to minimize file size and annotated to provide a clear description of the clinical problem. Typically this is done with a graphics package, but in fact a relatively limited number of functions are required. These include cropping, annotation, rotation, brightness, contrast, color balance and conversion to black and white.

JPEG compression generally works well for clinical and pathology images, but there is theoretical and practical evidence that image compression based on wavelet algorithms is more effective for storage and transmission of x-rays¹⁴. Compression ratios of up to

30:1 have been achieved without significant loss of diagnostic quality in some studies¹⁵. Several implementations are now available in Java and C code. While these systems have unique file formats, the JPEG2000 image specification is being launched to provide a standard format. However to use alternative compression techniques it is necessary to export data in a loss-less file format such as TIFF.

Improving usability and data quality

The usability of the software by staff with limited IT skills may be the main barrier to wider adoption of IT systems. Overcoming this requires simple interfaces and careful testing with different cultural groups. Also, while clinical data may be entered as free text in an email program, it can be useful to structure this information to ensure a comprehensive description. This is particularly important with store-and-forward telemedicine referrals from remote areas where it may be difficult or impossible to discuss the case by telephone. Questions tailored to the specialty involved such as dermatology or pathology should help to ensure complete data collection particularly for novice users.

Security and confidentiality

Typical email systems do not provide adequate security and confidentiality for clinical data. Two standard approaches are commonly available. With "secret key" encryption (such as the RC4 algorithm) the sender uses a key or password to encrypt data. The receiving person uses the same key to unencrypt the data. This provides a reasonable level of security as long as the sending physician can contact the specialist at some point to exchange the key. Public Key Encryption (PKE) is more secure⁷ but slow, and requires better infrastructure. An alternative design is to upload digital images directly to a Web server through a browser. This allows the use of the Secure Socket Layer Protocol PKE for data security. However it does not easily permit image processing, and requires a reliable and fairly fast Internet connection.

Results: functionality of Telemedmail

Figure 1 illustrates the data requirements and functions of the program. TeleMedMail allows the user to import image files and view them. Functions are provided for cropping extraneous material, rotating the image and adjusting the compression of the image by the JPEG or wavelet compression algorithm. The annotation view allows the user to mark or place a box around features of interest. An additional block of pixels is then added to the bottom

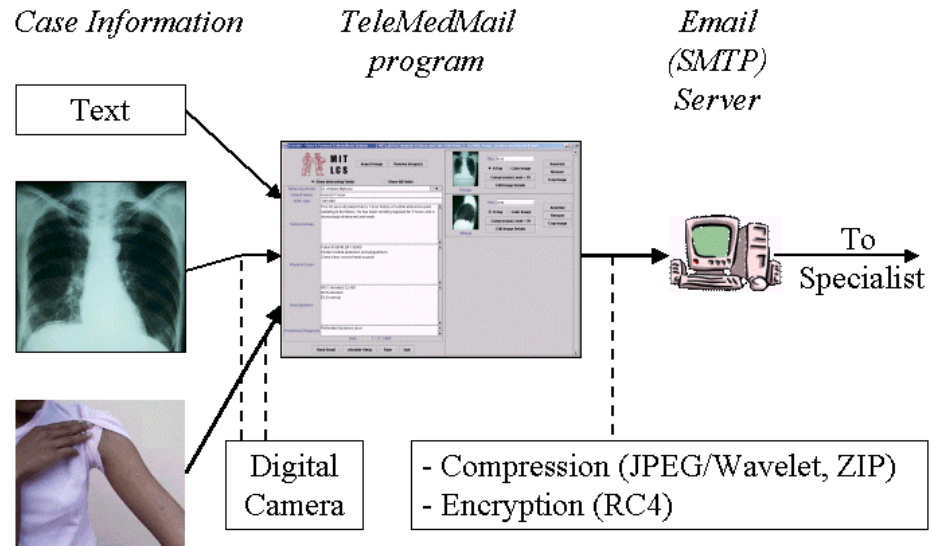


Figure 1. Organization and processing of data for email based telemedicine

of the image, containing text that identifies the patient and lists any annotations. JPEG and GIF images are currently accepted. Text on the patient's history, physical exam and investigations is entered in text fields that may be customized for particular specialties. When the case is sent, TeleMedMail generates an HTML page containing the textual description of the case and thumbnail sized views of the clinical images (figure 2).

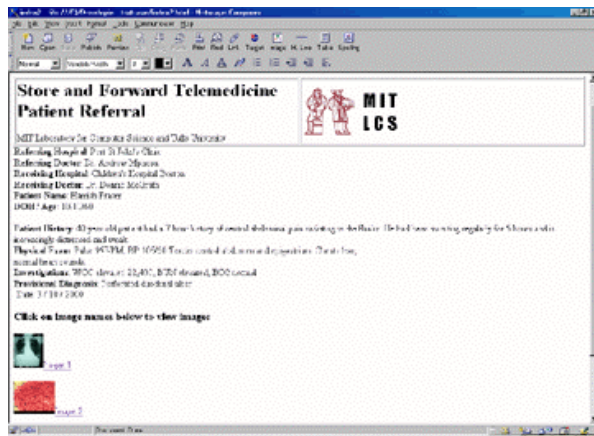


Figure 2. HTML case as received by the specialist

Compression and security

A completed case consists of the HTML page, any attached images, a brief referral email to the specialist and a copy of the image viewer program (described below). These files are incorporated in a Zip archive which is attached to the email. The user may optionally have the data encrypted with the RC4 "secret key" encryption algorithm.

Receiving and reviewing cases

The mode of use of the TeleMedMail program depends on the infrastructure and experience of the healthcare workers using it. The simplest approach is point-to-point email between two physicians, typically a remote physician or healthcare worker and a specialist in a hospital or teaching center. In this circumstance the sender simply enters the e-mail address of the specialist and sends the case by

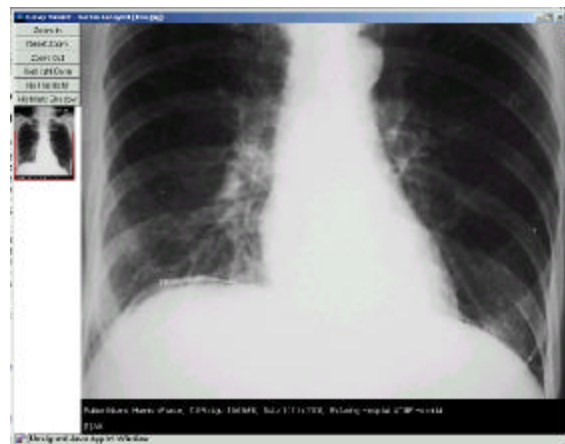


Figure 3. The image viewer applet

Internet or store-and-forward email. The specialist unzips the archive attached to the email and opens the HTML page to review the case. If the archive is encrypted, the Java applet requests the password. Figure 2 shows an example HTML page with image thumbnails incorporated. This page includes a "mailto" tag to simplify reply messages. Anonymity can be achieved by using only the patient's identification number in the reply email, though an encrypted reply email approach is being developed.

Image viewer

Images that have a smaller number of pixels than the display of the reviewing computer can be effectively viewed in a Web browser. However resolutions of recent generations of digital cameras exceed computer displays. Web browsers cannot show these images in their entirety and also lack the facility to change brightness and contrast. We have developed an image viewer as a Java Applet, which reads a JPEG image specified by an HTML page (figure 3). The Applet allows the user to magnify or reduce the image, and to navigate the viewable area of the image with a thumbnail view and cursor shown on the upper left. Brightness and window levels of the image can also be adjusted. Images are viewed on a standard PC monitor typically at 1025 x 768 resolution which is generally adequate for x-rays¹⁶.

Language support

As the TeleMedMail program is intended for use in a wide variety of locations, it is designed to simplify internationalization. All visible names and labels in the program are contained in a text file loaded when the program starts, English, Spanish and Portuguese are currently available. We are also exploring the use of Unicode to support non-roman scripts.

Technical details

The TeleMedMail program is written in Java 1.2 to facilitate cross platform use, and has been tested on Linux and Windows machines. A Java Run-time Environment needs to be installed on the sending machine (a 5 MB file). The program acts as an SMTP email client, and the attached files are encoded using the MIME protocol. A unique number is generated for each case to simplify case tracking and archiving of previous cases on the sending machine. The viewer Applet is a 22 kilobytes JAR file, written using the Java Advanced Windowing Toolkit (AWT) to ensure backward compatibility with Netscape or Internet Explorer Browsers, version 4 onwards.

Discussion and future development

The TeleMedMail system currently functions as a stand-alone program with the image viewer either sent in the Zip archive or located on a Web server. Several additions are being made to the system as detailed below, and will be complete by early 2001.

Linking to electronic medical record systems

While the point-to-point email approach is valuable when there is very little infrastructure, it is not suitable for managing a large volume of cases. Ideally the specialist should be able to bring up the case as part of an integrated electronic medical record

system (EMR). This would avoid the need for the specialist to open the Zip archive and allow for more sophisticated security. The current system can be integrated with an EMR by the addition of a component program to act as a POP email client. This program will poll the email server at regular intervals for cases sent to the hospital. The emails can then be processed and the data entered into the electronic medical record system using the patient ID number as the key. We are building such a system to support the management of drug-resistant tuberculosis in remote areas. This uses a database backed Web site to store clinical and laboratory data. Clinical images or x-rays received from the TeleMedMail program will be stored alongside other clinical data entered through the Web. An additional benefit of such a system is the facility to generate an automatic acknowledgement email to the referring physician. This is an important issue with unreliable networks such as those in sub-Saharan Africa.

Image annotation

The current annotation mechanism is simple and flexible. However changing the underlying image is not ideal as it may obscure important detail, and adding extra pixels increases the image file size. A better approach is to store the details and locations of any annotations and send them as a data file with the image. Using a modified viewer applet the annotation data can be displayed on the image and toggled on or off. This feature is currently being tested with the data stored in an XML file, which can be interpreted by a medical record database as well as the viewer.

Evaluation

The program is being tested to ensure reliability and ease of use in pilot studies in Peru, Brazil and South Africa. As a key goal is to minimize training requirements, quality of instructions and very simple operation are being emphasized.

We are also experimenting with the optimum lighting and camera settings for digitizing x-rays. While it is possible to acquire adequate images by photographing an X-ray taped to a window, the best results are achieved with the camera on a tripod with the x-ray on a bright light box¹². To test the diagnostic quality of such images, 24 chest xrays imaged at 1536 x 1024 pixel resolution by a digital camera (Kodak DC265, Kodak, USA) were reviewed blindly by three radiologists in Boston, USA to determine their diagnostic quality. 60 of 63 readings were correct in this small study¹⁷. A larger trial was performed in South Africa in which 100 xrays were digitized with a 1024 x 768 pixel digital camera (Mavica FD88, Sony, Japan). The readings were

compared to those made with the original films. 96% of the images were considered of diagnostic quality, and in 94% of these, the readings were correct⁹. We are currently carrying out studies of image quality in Boston, South Africa and Peru, using the TeleMedMail system and a 2048 x 1535 pixels resolution camera (Camedia 3030, Olympus, Japan).

Future development

In addition to work on the electronic medical record we are planning to add a simple viewer and management tools for ECG traces. A more advanced feature that is planned is the ability to transmit short ultrasound videos. This requires sophisticated image compression but could play crucial role particularly in cardiology, an increasingly important field in developing countries.

TeleMedMail is intended to be a simple, reliable and very economic option for performing telemedicine in remote areas. The use of Java to facilitate platform independence should simplify deployment. Software costs are often prohibitive in developing countries and can be greater than the actual PC hardware. TeleMedMail can run on Linux, potentially cutting license costs to zero, but is also able to run on the more common Windows™ machines. We hope that other developers will be interested in modifying and developing the code for their own communities and translating the interface into other languages.

For further information and software demonstrations see: <http://www.telemedmail.org>

Acknowledgements:

Sean Doyle, Libby Levison, and Candy Day. International Training Program in Medical Informatics: Grant # 1 D43 TW01083-01. The Bill and Melinda Gates Foundation through a grant to the Program in Infectious Disease and Social Change, Harvard Medical School, Boston, USA

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