Telemedicine: challenges and opportunities

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Abstract. Telemedicine is many things to many people. Only until a few years ago, telemedicine was equated to video teleconferencing between physicians, while nowadays, perhaps the most active area in telemedicine is the store-and-forward model. There is a big shift from private and dedicated modes of communications to connectivity through the Internet. Presented is a collection of applications that provide snapshots of this diversity. The key technical challenges identified from these experiences are connectivity and integration. Also, at issue are the evolution process through which a telemedicine application evolves and the ability to choose the right set of technology for the diverse type of telemedicine applications. With the projected improvements in speed and quality of the Internet, wireless communication, and personal computational devices, it is expected that various concepts of telemedicine will develop into standard practices in tomorrow’s health care.

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1. Introduction

Telemedicine, in one form or another, has been practiced for over forty years. At the simplest level, a nurse providing clinical advice over the telephone is practicing telemedicine. Today, however, we think of telemedicine applications that employ advanced image and video as well as audio capabilities. These technologies can range from high-resolution still images (e.g., X-rays) to sophisticated interactive teleconferencing systems. Telemedicine now has the potential to make a difference in the lives of many Americans. For example, telemedicine can improve the delivery of health care in America by bringing a wider range of services such as radiology, mental health services, and dermatology to communities and individuals in under-served urban and rural areas. In remote rural areas, where the distance between a patient and a health professional can be hundreds of miles, telemedicine can mean access to health care where little had been available before. In emergency cases, this access can mean the difference between life and death. In particular, in those cases where fast medical response time and specialty care are needed, availability of telemedicine can be critical. In addition, telemedicine can also help attract and retain health professionals in rural areas by providing ongoing training and collaboration with other health professionals.

Cybermedicine, if defined as medicine in the Internet, is quite distinctive from the telemedicine as we know today, although there are overlapping issues, especially as the Internet can also be used (though limited) as a medium for telermical applications. While the context in which telemedicine have been conceived until now focuses primarily on exchange of confidential clinical data with a limited number of participants, for the most part between patient and physician or between physician and physician, there is a global exchange of open, non-clinical information, mostly between patient and patient, sometimes between patient and physician, and between physician and physician. Telemedicine for the most part is applied to diagnostic and therapeutic medicine, while cybermedicine is applied to preventive medicine (prevent the occurrence of disease, for example by health education, as well as in the reduction of the consequences of disease, for example by information exchange among patients through newsgroups, websites, or via E-mail) and public health. With the improvement of Internet connectivity, these two applications will merge and become what can be called e-medicine. All the telemedicine applications may be practiced through the Internet including the interactive video and store-and-forward applications. For the purposes of this paper, we will adopt the Institute of Medicine’s definition where ‘telemedicine’ refers to the use of electronic information and communications technologies to provide and support clinical health care when distance separates the participants [17].

Telemedicine can be divided into three areas: aid to decision-making, remote sensing, and collaborative arrangements for the real-time management of patients at a distance. As an aid to decision-making, telemedicine includes
areas such as remote expert systems that contribute to patient diagnosis or the use of online databases in the actual practice of medicine. This aspect of telemedicine is the oldest in concept. Remote sensing consists of the transmission of patient information, such as electrocardiographic (ECG) signals, X-rays, or patient records from a remote site to a collaborator at a distant site. It can also include the transmission of grand rounds for medical education purposes or teleconferences for continuing education. Collaborative arrangements consist of using technology to actually allow one practitioner to observe and discuss symptoms and other aspects of cases with another practitioner whose patients are far away. Two-way workstations that provide smooth digital motion pictures have been integral to the long distance, real-time treatment of patients. As new technology is created and used effectively, collaborative arrangements are the future of telemedicine.

In the next section, we will discuss how telemedicine has evolved over time. In Section 3, a diverse collection of telemedicine applications are presented. A discussion on the technical issues based on these experiences is given in Section 4. We conclude in Section 5 with some outlooks of telemedicine in the future.

2. The emergence of telemedicine

The existence of telemedicine can be traced back to the first uses of the telephone. For example, in 1877, twenty-one local doctors built one of the first telephone exchanges to allow easier communication with the local drugstore. Although these early efforts fit the broad definition of telemedicine (use of telecommunications technologies to deliver health care), modern characterizations of telemedicine have occurred within the last thirty years.

Lovett and Bashshur [24] divided the development of telemedicine into three stages. The first stage was characterized by pioneering efforts with few public or private resources to support them. The second stage, between 1965 and 1973, was marked by deliberate efforts towards research and development and received short-term federal support. The third stage continued from 1973 through 1979 and involved evaluation by interdisciplinary teams with social scientists and specialists in medical care organization, planning, and delivery included for the first time. The Space Technology Applied to Rural Papago Advanced Healthcare (STARPAHC) program, a 20 year effort, marked the intersection and application of telecommunications technology expertise gained from the Space Program to the problem of delivering medical care to the Papago Indian reservation. This 3.3 million-dollar project advanced the understanding of how telemedicine applications could alleviate many of the access concerns related to healthcare delivery. Evaluations of these early telemedicine projects suggested that the technology was reasonably effective in transmitting the information necessary for most clinical uses and that patients were generally satisfied with their treatment [4,17].

Unfortunately, the telecommunications infrastructure of the 1970s (and prior) that was necessary to transmit high resolution images, video and audio signals was scarce and prohibitively expensive [1,2]. The newness of the technology by users and experimenters resulted in inefficiencies and was met with a general reluctance to adopt [1,12–14]. Funding agencies, in their haste to discern a cost effectiveness model in the face of escalating technology costs, pulled the support from these demonstration projects. Without government funding, the projects failed [1,2].

While many of the early attempts for telemedicine could not be sustained, there are some examples of highly successful programs using very simple technologies. One such example is the radio medical network in Alaska. Health Aids trained to manage patient encounters following strict guidelines established by the Indian Health Service. They are authorized to administer care by the village doctors who are located in larger towns hundreds of miles away. At a given time of the day, the Health Aids make radio calls to the village doctors and review the patient encounters. The doctors can then instruct the Aids to deliver certain treatments or other follow up care. In serious situations, patients can be interviewed directly by the doctors. This system, though primitive, has been able to improve the quality of care throughout the remote villages in Alaska, illustrating how simple technologies can be useful in certain environments.

The 1990s have witnessed the culmination of a number of factors that support the resurgence of telemedicine applications. These factors include the national push for information super highways, advances in high-speed telecommunication, introduction of interactive video teleconference systems, and the growing interests in integrated healthcare systems.
A very significant recent event in telemedicine may be the introduction of video teleconferencing systems (VTC) [31] into the health care environment. These systems were originally developed to facilitate business meetings between people separated by long distance. As costs declined and quality improved, VTC soon captured the imagination of medical users and was implemented as a means of delivering health care. Teleradiology, although a form of teledmedicine, could not be as readily launched for some years due to exorbitant costs of special equipment for high resolution and fine shades of gray images and massive data volume. The applications for interactive face-to-face consultations facilitated by VTC, however, transcended many clinical disciplines. Although not originally designed for health care applications, VTC systems were quickly integrated with medical peripherals such as electronic stethoscopes, endoscopic cameras, and other devices that provided additional diagnostic capabilities to telemedicine practitioners.

Telecommunication connections facilitate collaboration and partnership among distinct entities and foster the emergence of new forms of virtual organizations [32,37]. These virtual organizations are no longer defined or limited by geographic boundaries or physical distance, but are facilitated through complex, high-speed telecommunication connections that allow face-to-face and data exchanges. As virtual organizations, integrated healthcare organizations can function effectively across distance and time.

Telemedicine faces different challenges depending on the needs of various sectors in healthcare. Patients demand that telemedicine improve the quality of care and access to specialists. Provider organizations, such as hospitals, demand that telemedicine be capable of reducing the cost of care. To some, telemedicine may offer opportunities to reduce the operating cost by consolidating and streamlining management of multiple facilities. Physicians and other providers may see telemedicine as a means to improve their financial standing by attracting more patients to their services. Others however, may see telemedicine as a threat. The payers are concerned that indiscriminant use of telemedicine may increase the cost of care without any improved outcomes. Many technological advances in medicine help diagnose, treat and prevent illnesses and their roles are generally well defined, but the role of telemedicine is often unclear because it does not directly diagnose, treats, or prevent diseases.

3. Diversity of telemedicine

Telemedicine is many things to many people. Only until a few years ago, telemedicine was equated to VTC, while nowadays, perhaps the most active area in telemedicine is the store-and-forward model. There is a big shift from private and dedicated modes of communications to connectivity through the Internet. Table 1 shows a number of illustrative telemedicine applications, and the technologies by which they might reasonably be accomplished [15]. Presented in this section are a collection of applications that portray this diversity in telemedicine.

3.1. Deployable radiology

The United States military has always been an effective proponent of digital imaging and teleradiology. A teleradiology network makes military medicine requirements simpler by eliminating both the need to deploy radiologists and the use of X-ray films. X-ray film requirements include storage of new, unexposed films, storage, use, disposal of chemicals and water for processing, and storage of films and reports, all of which demand considerable amount of resources and logistics undertaking. The Imaging Science and Information Systems (ISIS) Center at Georgetown University Medical Center recently collaborated with the US Army in developing Deployable Radiology (DEPRAD), an off-the-shelf teleradiology network for the peace-keeping mission in Bosnia [22]. The network was part of Operation Primetime III [41]; a project to deploy advanced communications and medical equipment to provide state-of-the-art medical care to the 20,000 US troops stationed there. The network encompasses three major sites: the 212th Mobile Army Surgical Hospital (MASH) in Tuzla, Bosnia, the 67th Combat Support Hospital (CSH) in Taszar, Hungary, and the Landstuhl Regional Medical Center (LRMC) in Landstuhl, Germany.

At the MASH in Bosnia, a radiology local area network (LAN) had been installed which supports the following three modalities plus film digitization: computed radiography (CR), computed tomography (CT), and ultrasound
**Table 1**

Examples of telemedicine applications and the technologies that might be used

<table>
<thead>
<tr>
<th>Telemedicine Application</th>
<th>Telephone/Radio</th>
<th>Facsimile</th>
<th>Email</th>
<th>Interactive Video</th>
<th>Store &amp; Forward</th>
<th>Data Transmission</th>
<th>Real-Time Telemetry</th>
<th>Virtual Reality</th>
<th>Telerobotics</th>
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</thead>
<tbody>
<tr>
<td>Informal “curbside” consult between providers</td>
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<tr>
<td>Transmission of EEG or electrocardiogram data</td>
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<td>Real-time interactive orthopedic examination and consultation</td>
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<tr>
<td>Transmission of diabetic patients' blood glucose data from home</td>
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<td>Asynchronous P -based dermatology consultation</td>
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<td>Psychiatric assessment of need for hospitalization</td>
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<td>Home health care services for hospice patients</td>
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<td>Transmission of physiologic data by EMT in an ambulance</td>
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<td>Interpreting a stroke patient's CT scan before administering TPA</td>
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<tr>
<td>Consultation with a physician by physician assistant</td>
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<tr>
<td>Home health care for persons with chronic conditions</td>
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<tr>
<td>Patient education</td>
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<td>Remote supervision of laparoscopic surgical procedures</td>
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<tr>
<td>Performing remote laparoscopic surgery</td>
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<td>Diagnosis of an astronaut’s acute illness during space flight</td>
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<tr>
<td>Trauma and emergency consultation for rural hospital staff</td>
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<tr>
<td>Management of patients with drug-resistant tuberculosis</td>
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</table>

(US). A schematic of the MASH configuration is shown in Fig. 1. The CSH configuration is quite similar. The LRMS installation was designed to receive images only from the MASH and CSH and display or print them as necessary. The clinical scenario is to acquire images using any of the three modalities listed above or by digitizing existing film. The images are then sent over a local area network to a Siemens workstation in the radiology for storage and viewing. Since there is typically not a radiologist at the MASH, the images are then transmitted to the CSH for primary diagnosis and archiving. Images can also be transferred to other display stations within the MASH depending on the patient location.

Several types of communication systems were used throughout the DEPRD network, which is shown in Fig. 2. A 10BaseT LAN was implemented to move images within the MASH and CSH. Wide area communications between LRMC and the MASH utilized microwave and satellite links. Images acquired at the MASH were sent via a microwave extension to a United States air base. The data were then relayed to Landstuhl via satellite connection. The communication between Landstuhl and the CSH was over E-1 lines (2.048 Mbps signaling rate) leased from the German and Hungarian telecommunication companies. Internet access was established at all sites.
A number of devices were required to establish the filmless radiology and teleradiology capability that linked the three medical facilities. In order to connect all of the equipment in a clinically useful network, the Digital Imaging and Communication in Medicine (DICOM) 3.0 standard was required [3]. While DICOM is fast becoming the standard of choice by most medical imaging vendors, limitations of the standard were realized. Among the DICOM implementations encountered, none was connected without modification to configuration files, software changes, patches by vendors, or operational changes [23].

3.2. A multi-center digital MRI network

The Center for Neurogentic Diseases of Kennedy Krieger Research Institute (KKI) at Johns Hopkins University, Baltimore, Maryland, in collaboration with the ISIS Center at Georgetown University, is developing a global MRI network.
network that allows participating sites to consult on adrenoleukodystrophy (ALD) magnetic resonance imaging (MRI) cases. Brain MRI and magnetic resonance spectroscopy (MRS) are the most sensitive indices for the evaluation of ALD therapies, but require the transmission of high quality images and the evaluation of these images by neuro-radiologists with extensive ALD experience. Due to the rareness of this disorder, this network is required to provide a sufficient number of patients for evaluating ALD therapies. This network will improve the ability of the participating institutions to evaluate ALD therapies.

Each participating site will electronically transfer MRI studies of ALD patients to the central clinical database at the KKI. The central database serves as a DICOM server, a storage-and-retrieval application that conforms to the DICOM standard for transmission of medical images (Fig. 3). The DICOM server provides the function of receiving and storing DICOM images as a DICOM Storage Service Class Provider (SCP). It will also respond to queries for the stored images as a DICOM Query/Retrieve (Q/R) SCP. The imaging modalities at the contributing sites are DICOM Storage Service Class Users (SCU), while workstations used by the radiologists to request the studies for review are DICOM Q/R SCU. Commands and data are exchanged between the provider and the users in the form of DICOM messages.

An important issue that needs to be addressed in transmitting and sharing patient data is patient confidentiality. Data received at the KKI will arrive with the patient identification information intact. Therefore, wherever possible, firewalls will be used to create virtual private networks (VPN) to protect the information being transmitted. Once data has been received, the identifying information will be stripped off and a system-generated identifier will be assigned. The central clinical database as well as the DICOM server will sit behind the firewall. While the DICOM protocol cannot pass directly through the firewall, due to limitations of current firewall protocols, a ‘secure hole’ will be opened in the firewall to allow the packets to pass through.

3.3. VTC based global patient care

The Office of Medical Services (MED) based in Washington, DC, operates, administers, and manages a worldwide health care program for employees and their families serving abroad with the US Department of State and other associated US Federal agencies. The clinical staff assigned to the MED’s Health Unit in Nairobi, Kenya, have presented extraordinary demands on MED Washington’s health care services and program planning as a result of the Embassy bombing on August 7, 1998. To address this demand, in part, the Department of State, in cooperation with the US Army Medical Research and Materiel Command (USAMRMC), established a telemedicine platform
linking the Department of State Health Unit in Nairobi, Kenya, to MED Washington in October of 1998. In addition to the telemedicine platform linkage, the Division of Medical Informatics of the State Department must sustain and expand telemedicine services to the Health Unit Nairobi.

The ISIS Center at Georgetown University Medical Center has been involved in the efforts with the responsibilities of project management support, engineering and technical operations support, and analysis and evaluation of the telemedicine services between the Health Unit at the US Embassy in Nairobi and the MED Washington.

Initially, the preferred mode of consultation was VTC between Nairobi and Washington primarily for clinical consultation, and Nairobi and the ISIS Center for technical support and project management. Regular biweekly meetings via VTC between the three sites were established. However, because of the high communications cost required for VTC that was provided via ISDN connectivity using satellite communication, the mode has shifted almost entirely to the more cost-effective store-and-forward model. An off-the-shelf telemedicine application, in conjunction with digital capture devices such as X-ray digitizer, dermascope, ENT scope, ophthalmoscope, and digital video camcorder was used to carry out physical examinations of patients and to send the acquired exams over a secured Department of State’s network. Although all communications are through a secured private network owned by the Department of State for obvious security reasons, the technologies employed are Internet compliant, such as HTTP, TCP/IP, and SMTP.

The major challenge in this project was not so much in the technical areas but in training and education; getting people in different parts of the world to adapt to a new mode of health care procedure.

3.4. Home health monitoring over the Internet

Telemedicine is no exception to being greatly influenced by the Internet. With the Internet connecting millions of households and virtually all institutions, it makes perfect sense to deliver health care services to patients’ homes over the Internet. A pilot project aimed at close monitoring of patients with chronic diseases is currently underway at the ISIS Center at Georgetown University Medical Center. The project currently focuses on two types of patients; patients with end stage renal disease performing Peritoneal Dialysis (PD) at home and those with diabetes. The primary goal of the system is to assist in the close monitoring of patients in their homes. The second goal is to provide relevant information to the patient so that they may become more self-sufficient, better informed about their disease and their health, and more compliant in administering their prescriptions.

The system aims to provide a single easy to use Web interface to all users. The patients will routinely upload their glucose readings, PD data, or other relevant information to a central database server. All data from monitoring devices will be uploaded automatically from the devices whenever the user logs on the Web site and connects the device to his/her computer. The patients can view previously entered data, their progress, and prescriptions through user friendly Web interfaces. The physicians need more complicated views and functions, some of which are readily available in commercial products. In order not to reinvent the wheel and to allow physicians to use the software they are already accustomed to, a couple of patient management software products are being integrated to the system. The challenge to this approach is in integrating the databases used by the different systems. A consolidated data model has been defined which serves as the data model for the central database and also as the reference model to which each of the other databases has to be translated into.

Smart agents are being developed and implemented to perform certain critical tasks including checking parameters and ensuring that they are within target ranges, reminding patients of upcoming appointments and prescriptions, and presenting new information and educational materials relevant to the current situation.

3.5. DBMS based medical conferencing

Most conventional teleconferencing systems work in a mode called ‘copy-and-synchronize’, in which the conference material must be prepared prior to the conference time and copied into local disk of every site [21,33]. In such setups, data are not directly retrieved from database at the time of a conference. Also, saving the conference result (proceedings) had to be done manually. A system designed and implemented at Seoul National University
Hospital, Seoul, Korea, aims to build a teleconferencing system that is tightly integrated with the multimedia hospital database [20]. By integrating the teleconferencing functions into the database client application, users can conduct teleconference sessions using the same database interface they would use routinely to retrieve patient data.

Figure 4 shows a conceptual depiction of the way this system works. The Shared Workspace is the database interface augmented with functions for teleconferencing, such as proceedings control and annotation. The teleconferencing system synchronizes all windows events such as movement of the mouse, push of a button, and input from the keyboard. This synchronization translates into sending the same requests (or queries) to the database server, thus resulting in synchronized presentation of data.

The following design objectives that were pursued in this project are relevant to most medical teleconferencing applications.

- A teleconferencing system must be directly integrated with the existing medical database application so that patient information needed for a conference, whether previously expected or not, may be dynamically retrieved during the time of a conference. The system must also be able to store and maintain the result (proceedings) of a conference.
- The teleconferencing system must be more than an interconnection of different applications. The system must provide an integrated shared workspace that allows participants to organize the various forms of conference related data and to present the materials systematically for better conferencing. The workspace should be flexible enough to meet various conference contexts for different medical communities.
- A teleconferencing system must support a unified view of a patient’s record that mimics a real-world patient chart. Since most conferences are held for a single patient’s case, it is important to have the system ready to present all information that is related to that patient’s case. Through the workspace, we can provide an integrated view of various patient data [34].

Database access and workspace synchronization are carried out over the Internet. The system also included a separate VTC setup through which the physicians talked and watched each other while manipulating the database together. However, the physicians quickly abandoned the interactive video and were comfortable with only the telephone to complement the conference session. This meant abandoning the ability to send real time visual images captured during conference, but the users did not see much added benefit that would warrant the cost and hassle accompanied in setting up a VTC session.
4. Technical issues

4.1. Telemedicine applications and technologies used

Table 2 shows the different technologies employed by the telemedicine applications presented in the previous section. Voice communication, including telephone, is a basic necessity for all the applications. In all the situations where Internet connection was available, including those where Internet was not the primary mode of connection, emails were so prevalent that not using them made little sense. Interactive video is obviously a good feature to have, yet the demanding cost makes the store-and-forward model more widely accepted in these cases. The Data Transmission column indicates whether data from monitoring devices were actively captured and transmitted in the application. In VTC applications, there is the need to synchronize presentation of data and motions in the user interface. As the Internet becomes available to more people and organizations, we see a shift from doctor-to-doctor teleconsultations over private networks to patient care telemedicine over the Internet.

4.2. Connectivity

A typical VTC application requires 2–4 ISDN lines (256–512 kbps) to a full T1 line (1.544 Mbps) capacity, depending on the quality of video. Figure 5 shows the different bandwidth requirements for different modes of communications. With the rates as high as they currently are, telecommunications costs represent one of the biggest portions of the operational cost of telemedicine programs. Although bandwidth requirements are decreasing as technology advances, interactive-video-level connectivity is not the type of bandwidth that an institution can afford to reserve for a handful of applications. More often than not we witness a telemedicine program being modified to exclude or significantly reduce the interactive video features that were the main theme in the initial stages of the program.

The VTC-based Global Health Project presented in Section 3.3 is an example where the VTC feature, which was central to the concept of the project, was all but abandoned in the later stage. Setting up sessions across different international time zones was a difficult task to begin with, but the high communication cost was the biggest factor influencing the change.

Table 2

<table>
<thead>
<tr>
<th>Telemedicine Application</th>
<th>Telephone/Radio</th>
<th>Email</th>
<th>Interactive Video</th>
<th>Store &amp; Forward</th>
<th>Data Transmission</th>
<th>Real-Time Sync</th>
<th>Connectivity*</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deployable Radiology</td>
<td>●</td>
<td>●</td>
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<tr>
<td>Multicenter Digital MRI Network</td>
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<td>Global Patient Care</td>
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<td>Home Health Monitoring</td>
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<td>DBMS Based Teleconferencing</td>
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* Private network (P) or Internet (I)

1 Doctor-to-doctor (D) or doctor-to-patient (P)
The DBMS based teleconferencing system in Section 3.5 is another example. In this application, all participants were within the same time zone, eliminating the time difference factor. The deciding factor in this case was the hassle involved in setting up the VTC. The communications and device requirements for the VTC are such that it is not economically possible to make every room VTC-ready. The physicians would rather sit in their own offices and engage in teleconferences with only their PCs and telephones rather than move to the VTC-ready conference room. Another factor is that the majority of the cases that physicians were interested in discussing with their colleagues were cases that had already been extensively reviewed locally. Most of the relevant tests and images have been taken and are available in the database, which can be browsed in a synchronized manner. In such cases, interactive video is no more than an expensive ‘video phone’ showing the picture of the other party.

It would be wrong, however, to conclude that the merits of interactive video is marginal in telemedicine. On the contrary, a careful examination of the above projects shows that abandoning VTC has been a compromise between the goals set in the beginning of the project and the cost and efforts involved in providing interactive video. A discussion or a consultation is likely to be more productive when the parties meet face-to-face, and if this is not possible, VTC is obviously the next best option. More importantly, there are situations where it is vital to see ultrasounds or ECGs as they are administered at the remote site. So, the problem is not that telemedicine can do without interactive video but rather it is too inconvenient and expensive. Communications cost is still too high for most VTC applications to be cost effective. Most VTC devices, such as the Coder/Decoders (Codecs), are still too expensive to be a part of an average ‘multimedia-enabled’ PC for the home and office.

With the trend towards physician-to-patient home health care [11,43], connectivity at homes is becoming ever more important for telemedicine. The Home Health Monitoring project described in Section 3.4 is an example of the growing number of applications in this direction. Anyone with a modem and a telephone line can have Internet access through an Internet service provider (ISP). However, most telemedicine services providing interactive physician-to-patient interactions require more speed and reliability than can be offered by this mode. Connections over ISDN and cable modems are two of the few modes that can provide higher speed and reliability. But, as Grigsby, et al. [15] observe, advanced telecommunications infrastructure is not available for many rural areas. Even for those areas where the necessary transmission media are available, they may be prohibitively expensive. There is also evidence of disparity between the rural areas in rates for similar level of transmissions. This is a serious situation given that the most effective use of home health telemedicine would be in the rural areas.

In order to realize the true potential of telemedicine, high-speed connectivity should be available in each room of a hospital and each household. One should be able to plug in any medical device to these outlets and feed images and videos to any designated PC or node on a local network or the Internet.
4.3. Integration

Telemedicine is an integrated application by nature. One must address the integration of image display, data presentation, human computer interface, data storage and management, network, communications, electronic and medical devices, etc. The software modules defined in a telemedicine system will likely include patient demographics data browser and editor, examination results display, image viewer and annotator, and teleconferencing. Some of these features are available in one commercial system or another, but it is very difficult to extract and then integrate these features from disparate systems that we end up inventing the wheel again. This has been a particular difficulty in the project described in Section 3.4 where two commercial systems for physicians had to be integrated with the newly developed patient system. Furthermore, the configuration of the integrated components, as well as the components themselves, must be dynamically changeable in order to cope effectively with different types of diseases, different stages of a patient, and the new and changing specifications of medical devices. Thus, as much as any integrated information system, a telemedicine system stands to gain enormously from software engineering technologies that provide a better way to reuse software codes, integrate functionality, and modify on the fly. Component-based software engineering technology and object request broker (ORB) architectures such as CORBA and CORBA-MED [16,18] seem to be efforts in the right direction, but their practical merits are yet to be seen.

Another dimension in the integration issue is data. A typical patient’s record will consist of demographics, physical exams, X-ray exams, blood and urine exams, and dietary and exercise information, all from different laboratories and clinics. A patient’s record kept in his/her primary care institution should be readily available when the patient checks into an emergency room in another state. This is a classical database integration problem with syntactic and semantic disparities to be resolved. The medical community was early to identify this problem and has been trying to address it [6,10,35]. Telemedicine simply magnifies and brings the problem to the forefront.

Software and hardware integration issues cannot be addressed without adopting standards. Standards are required for almost all aspects of telemedicine such as EMR (Electronic Medical Records) and their exchange, device-to-device transmission, real time collaboration and constraints, software interface and integration, and teleconference functions such as synchronization and web annotation.

4.4. Framework of telemedicine development

As the examples in the previous section indicate, the term telemedicine alone does not adequately describe the specifics of any one application. Telemedicine applications face different barriers and challenges based on the goals of the project, the technologies incorporated, and the context of the users. The field of telemedicine is facing many of the dilemmas that confront any new field that is created through technological innovation. The technology must evolve through its own development, while creating applications that help, to then define the technology’s own future growth. In this way, the technology helps to define the applications, while at the same time, the applications help to define the technology. This technology development process involves the following four basic stages [27].

Stage 1 – Development of Basic Technological Capabilities

Telemedicine will require a new array of technologies in sensors, imaging, computer-controlled devices, communications, voice driven systems, complex and intelligent database and network technologies. During Stage 1 we see the development of new types of technology involved in various stages of the health care delivery process. These technologies may involve information capturing, information transmission, or interpretation. As these technologies develop, innovative practitioners develop ways in which the technology can be incorporated into their practice.

Stage 2 – Development of Relevant Applications

Stage 2 describes the initial development of applications to meet the capabilities of new technologies. As these technologies begin to be used within various health care applications, practitioners can envision ways in which the innovation can be adopted on a grander scale. As more research is developed to support the use of specific
telemedicine applications, greater support within specific medical disciplines and federal agencies will evolve. In this stage, the acceptability of the technology for specific applications can be validated and clinical efficacy demonstrated.

**Stage 3 – The Integration of Technical Applications within a Complex Environment**

Telemedicine applications realize the third stage of the technology development process as concerns about reimbursement, licensure, credentialing, and standards continue to be debated at the national level. Our laws, credentialing systems, and reimbursement mechanisms were not created with a virtual environment in mind. Unfortunately, instead of recognizing the uniqueness offered by virtual space, our licensing, credentialing and reimbursement systems have tended to ignore this new environment. Instead, we force our physical world laws into virtual space. Studies suggest that the most common specialties using telemedicine as a means of providing care were mental health, emergency/triage, cardiology, dermatology, and surgery respectively [13]. This suggests that these five specialties are more amenable to telemedicine applications than others, although another research [25] suggested that telemedicine use might be more practitioner specific than specialty specific. In either case, adopting a new technology into the way of practicing medicine is a major undertaking that deserves more recognition than is currently given within the medical and engineering community.

**Stage 4 – The Transformation of the Operating Environment**

Stage 4 describes the transformation of the environment to incorporate the new telemedicine applications. The complex issues of the environment, coupled with the demands of the applications create a new focus on the needs that are present and the solutions that are available. As technologies become integrated within specific applications, new technologies develop that can improve the efficiencies and quality of the existing system. At this point the cycle begins again. In some cases, the telemedicine innovations will evolve within an existing health care delivery environment. In other cases, telemedicine innovations will expand the environment to new locations. An example of this expansion can be seen in the use of telemedicine within the home.

4.5. Determining the technical requirements of a telemedicine application

Many technical approaches exist for providing telemedicine services. Choosing the appropriate equipment for a telemedicine project requires careful analysis. The following questions help guide the technical analysis [29].

1. **What technical functionality does the project require?** The needs assessment drives the answers to this question. Not all telemedicine projects require video conferencing. Most technical services come in a variety of flavors. Choices increase daily but are constrained by the services a project proposes to deliver.

2. **What telecommunications bandwidth does the project require?** Making a selection of equipment to meet a project’s needs usually establishes a minimum requirement for bandwidth. The relatively slow rate of image transmission over the Internet yields choppy, poor resolution images unsuitable for clinical diagnosis, while the bandwidth may be acceptable for home health monitoring applications (see Fig. 5).

3. **May equipment be purchased off the shelf or does it require custom development?** As the market for telemedicine products has developed, conventional, off the shelf products have become increasingly available for many telemedicine applications. Moreover, standard products such as video conferencing equipment or personal computers compose segments of telemedicine networks even though not specifically designed for medical use.

4. **Is the technology known or must it be learned?** The users in a telemedicine project must develop expertise in using the equipment and services. All projects should include training for prospective users but should also evaluate the relative complexity of proposed technology as a factor in the likelihood of successful use.

5. **Does the project require new infrastructure or technical capability?** Many telemedicine projects begin as freestanding efforts that require installing dedicated or specialized communications infrastructure. As organizational information systems develop and Internet based applications emerge, telemedicine projects will use common infrastructure at different levels of the global communications network.
6. **Is technical support available in-house or must it be purchased?** Few telemedicine applications are ‘plug-and-play’, thus requiring technical support at some level. Projects vary in their support requirements and in the availability of suitable personnel in the organization.

5. **Conclusion**

The Internet is here to stay. We expect the future to bring us a ‘ubiquitous Internet’ where everyone is connected to everyone everywhere. The successful efforts in advanced projects such as the Internet2 [40] and Next Generation Internet [8] indicate that the future of Internet promises to be faster and more reliable. For telemedicine, this means more options to more people. It is expected that the majority of telemedicine applications of the future will operate over the Internet instead of private networks. Technologies such as Virtual Private Network (VPN) will make peer-to-peer type telemedicine over the Internet less risky. Homes in certain parts of the world are already experiencing high speed Internet connection through digital subscriber lines (DSL) and cable modems, albeit at high prices. The advance in compression and communication technology, coupled with the fierce competition within the communication industry, will bring down communication charges. This will allow bandwidth hungry features such as interactive video to become affordable basic features of almost all telemedicine applications.

Already people in Japan and Netherlands are enjoying wireless digital phone services with data communication rates of 28 kbps or higher [9]. Wireless data communications at the personal level will be prevalent in the near future. It is perceivable that laptops, PDAs, and other mobile devices will be our main tools for Internet access. Mobile access standards such as the Wireless Application Protocol (WAP) [42] will enable such a transition and mobile satellite communications will allow global reach of voice and data services. This will open a new dimension of options for telemedicine applications. Paramedics will be able to care for patients at the site of an emergency with (almost) full connection to the hospital systems and resident physicians, and true uninterrupted patient monitoring and care can be realized around the clock. Pilot projects at the Mayo Foundation, Rochester, MN, and St. Elizabeth Hospital, Appleton, WI, have already successfully demonstrated the concepts using two way pagers [36].

Coupled with wireless communications, intelligent and convenient end-user devices will bring true mobility and interactional constancy. Wearable computers are expected to play important roles in future telemedicine. The goals of a wearable computer are to be mobile, to augment reality (not to replace nor to simulate), and to provide context sensitivity [7]. One application would be a nurse wearing a special pair of eyeglasses, where specific information about the prescription and treatment for the patient he/she is seeing will be presented either on the glasses or through the ear-piece. Another example is of an intelligent wristwatch that will constantly monitor the vital signs of a patient and alarm him/her of any concerns over the portable stereo headphones. There will be no more manual uploading or typing of the measurements from the patient monitoring devices.

We also envision medical devices being able to talk to each other, without a web of cables connecting them, by use of technologies such as embedded wireless where a high-speed wireless transceiver is embedded in every processor chip [30]. For example, without any hookups or cables, endoscopic images can be fed into a desktop computer, which in turn sends the data over a wireless network to a consulting physician. The consulting physician would be able to control the various monitoring devices that are set up in a remote operation room.

Advanced software technology, such as mobile agent technology, will evolve to meet the needs of large complicated systems. Mobile agents are active objects that can migrate autonomously from computer (device) to computer to perform computations on behalf of their owners, either users or programs [19]. The mobile agent paradigm brings the computation where the information is stored or is generated in cases of real time monitoring. One application of this technology is in dynamic customization of patient devices. This ability to upgrade and reprogram user devices over the network should drastically reduce the maintenance cost of doctor-to-patient type telemedicine applications. A mobile device deployed need not be programmed to cope with all possible scenarios but only be able to accept mobile agents as necessary. The mobile agent paradigm is only one of a list of innovations that we expect will provide a means to build dynamic and adaptive software systems that are maintainable.
Home health care is already one of the most important areas of telemedicine. Researchers argue [43] that the home health care environment must, first and foremost, be easy and comfortable. Their applications must be unobtrusive and, preferably, transparent. The devices and technology must be easy to use. It is indeed possible to design, manufacture, install, and implement medical and health care technologies which are simpler and easier to use. The home must remain a home, and not look like an intensive care unit or an emergency room. Product design should be using a ‘consumer model’ rather than a ‘medical model’. Appropriate and affordable communication technologies and networks are vital to home health care. The need and challenge is to seamlessly connect home health care monitors, sensors, and devices to these communication systems and thus to the various professional care providers.

Telemedicine is expected to enjoy a 40% growth in the next 10 years and by 2010, telemedicine will represent 15% of total health care activities [38]. Advances in telecommunication and network technology will bring closer the virtual society, and telemedicine will play an essential role in health care in this newly defined society. There are exciting challenges and opportunities in exploiting available technologies and in shaping the future of technology. With continued efforts in this dynamic and blended field of health care and advanced technology, telemedicine will loose meaning as a separate field of study as its concepts and applications become standard medical practices, at which point it will have achieved its final objectives.

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References


