

Evaluating a Web-Based Interface For Internet Telemedicine

CORINNA E. LATHAN, Ph.D.,¹ DAVA J. NEWMAN, Ph.D.,² MARC M. SEBRECHTS,
Ph.D.,³ AND CHARLES R. DOARN, M.B.A.⁴

¹Biomedical Engineering, The Catholic University of America, Washington, DC 20064

²Department of Aeronautics and Astronautics, Massachusetts Institute of Technology,
Cambridge, MA 02139

³Department of Psychology, The Catholic University of America, Washington, DC 20064

⁴Aerospace Medicine Division, Office of Life and Microgravity Sciences, NASA Headquarters,
Washington, DC 20546

Address for Correspondence:

Corinna E. Lathan, Ph.D.
Biomedical Engineering, Pangborn 104b
The Catholic University of America
Washington, DC 20064
Phone: 202-319-5095
Fax: 202-319-4499
email: lathan@cua.edu

ABSTRACT

Objective: To introduce the usability engineering methodology, heuristic evaluation, to the design and development of a web-based telemedicine system.

Materials and Methods: Using a set of usability criteria, or heuristics, one evaluator examined the Spacebridge to Russia web-site for usability problems.

Results: Thirty-four usability problems were found in this preliminary study and all were assigned a severity rating. The value of heuristic analysis in the iterative design of a system is shown since 1) the problems can be fixed before deployment of a system and 2) the problems are of a different nature than those found by actual users of the system.

Conclusions: There is potential value of *heuristic* evaluation paired with *user* testing as a strategy for optimal system performance design.

INTRODUCTION

Despite the exponential growth in the number of telemedicine projects and systems, relatively little attention has been paid to the human factors issues associated with designing such systems. However, the design of the human-computer or human-technology interface is the key to optimizing human performance.

Historically, human factors has been embedded in aerospace engineering with NASA playing a leading role. Therefore, NASA has supported this effort to apply human computer interface (HCI) design principles to the field of telemedicine. In particular, the NASA funded web-based project, Telemedicine Spacebridge to Russia is currently going through an iterative design process with feedback from users as well as usability experts.

Spacebridge to Russia - Internet-Based Telemedicine Testbed

In the context of ongoing human space flight activities with Russia, NASA continues to evaluate new approaches for enhancing the delivery of health care in spaceflight [1]. To date, many telemedicine testbeds have relied on expensive, dedicated telemedicine studios, that are not easily accessible to physicians when they need the service. In addition, tremendous gains have been made in the evolution of information systems and computer networks.

From September 1993 to June 1994, NASA directed the Spacebridge to Armenia [2] and the Spacebridge to Moscow [3], which enabled medical consultations between countries using both US and Russian satellites. Capitalizing on this work, NASA has partnered with academic and clinical sites in the US and in Russia to establish a telemedicine testbed for the evaluation of Internet telemedicine in operational and educational settings, called Spacebridge to Russia. It is a collaborative effort between NASA, the Institute of Biomedical Problems in Russia, and the Space Biomedical Center for Research and Training at Moscow State University.

At the conclusion of the Spacebridge to Moscow project, NASA recognized the need for reliable, inexpensive communications. It established a network based on the world-wide Internet infrastructure between NASA field centers and clinical and academic sites in the US and Russia. Each participating site was equipped with a Silicon Graphics, Inc. (SGI) Indy UNIX-based multimedia workstation. These workstations, linked via the Internet, also utilize a graphical user interface (GUI) on the World Wide Web (Web) for entering patient information and a video conferencing tool called multicast backbone (Mbone). Mbone allows the a user to multicast or transmit live video to multiple workstations as well as use additional capabilities such as a whiteboard function. The GUI allows clinicians to prepare a clinical case using a standard protocol, including text, data, video, still images (e.g. radiology, pathology) and audio from a desktop and make it available to clinicians world-wide for consultations using the Internet.

This testbed demonstrates the utility of incorporating multimedia and Internet technologies into medical consultation and focuses on a store-and-forward modality. It also demonstrates the utility of conducting video conferencing between multiple sites for the purpose of supporting medical education.

Heuristic evaluation

The potential impact of the Spacebridge project as a web-based tool to deliver medical care or medical education worldwide has made it especially important to ensure its usability. Human factors (or usability) engineering consists of a wide range of techniques that can serve to improve the interface design. These various techniques vary in their cost, time and complexity. User testing can be especially informative, but is also time consuming. Here we focus on one approach, heuristic evaluation, a method for finding usability “problems” in a user interface design by having examiners analyze the interface using a list of usability principles or heuristics and

listing violations of these principles. The problems found are then rated for their severity ranging from simple aesthetics to “show-stoppers.” Heuristic analysis is particularly appropriate for evaluation of a developing project such as Spacebridge to Russia because it quickly provides feedback than can be integrated in to system development. This paper demonstrates the application of this approach to the Spacebridge project.

METHODS

Procedure

The Spacebridge to Russia website was evaluated using Nielson’s [4] list of ten general heuristics for evaluating interfaces and considered Levi and Conrad’s [5] list of eight heuristics that were then adapted for web-based interfaces. The heuristics are described below with additional comments that help apply the heuristics to web-based interfaces. One evaluator did a heuristic evaluation and all authors agreed on a severity rating based on the scale below. The resulting usability problems found through the analysis were grouped according to heuristic and severity rating for evaluation.

*Usability Heuristics**

1. Visibility of system status and function

The user should always be able to know what is going on through appropriate feedback. (WEB: Download times of information and whether or not information is accessible should be evident).

2. Speak the users language

* Adapted from Nielson (1994) and Levi and Conrad (1996).

Use words, phrases and concepts familiar to the user. Use metaphors that are consistent with the real world. (WEB: Familiarity with specific characteristics of web structure should not be assumed).

3. User control and freedom

Users should be able to explore without the fear of losing information or making an irreversible mistake. Support undo and redo functions. (WEB: Ability to determine where the user is).

4. Consistency and standards

Terminology and graphics indicating particular concepts should be consistent throughout the system. (WEB: System function should match accepted web standards).

5. Error prevention

System design should prevent predictable mistakes. (WEB: A user should not be allowed to enter an invalid item in a search function).

6. Recognition rather than recall

The users' memory load should be minimized by making actions and objects visible. (WEB: Users should not have to rely on key information from previous pages).

7. Flexible and efficient access

Allow inexperienced and experienced users easy access to information. The most frequently accessed information should be most prominent. (WEB: Information should be organized with progressive level of detail and "chunked" so that information about one topic fits on one page. Allow users to easily navigate between related topics).

8. Aesthetic and minimalist design

Eliminate information that is irrelevant or distracting from the primary tasks. (WEB: Links and multimedia (backgrounds, graphics, animation, etc.) should be relevant).

9. Useful error messages

Error messages should inform the user of a problem as well as the appropriate solution.

10. Help and documentation of new information

The user should be able to access help easily and efficiently. (WEB: Information should be kept current).

Severity Rating Scale

A five point severity rating scale [3] was applied to each of the usability problems found by heuristic evaluation. The ratings are based on a combination of the frequency, impact, and persistence of a problem. Frequency refers to how common or rare the problem is. The impact refers to how easy or difficult it would be for the users to overcome the problem. Persistence assesses whether the users can overcome the problem once they know about it or will they repeatedly be bothered by the problem.

- 0 - May not be a problem—others may not agree that this is a usability problem at all
- 1 - Cosmetic problem only—need not be fixed unless extra time is available on project
- 2 - Minor usability problem—fixing this should be given low priority
- 3 - Major usability problem—important to fix, so should be given high priority
- 4 - Usability catastrophe—imperative to fix before product can be released.

RESULTS

A total of 34 usability problems were found by the evaluator. Problems were found for all ten usability heuristics with the highest number (eight problems) for “Flexibility and efficient access” and the least (one problem) for “Error prevention.” Figure 1 shows the number of

problems found for each heuristic. Figure 2 shows the problems broken down by severity rating. It is easy to see that the majority of problems were rated a 2, minor usability problems.

****FIGURE 1 ABOUT HERE****

****FIGURE 2 ABOUT HERE****

Figure 3 shows the Spacebridge to Russia “welcome” or “home” page that will be used to illustrate the types of problems found. Table I lists nine problems found on the welcome page along with the usability heuristic and severity rating. The first problem is that the functionality of all of the graphics is not clear. Only the 14 buttons are clickable, but many of the other graphics appear to be active. The second problem is that all 14 buttons are given equal importance which doesn’t allow efficient access to key information. Also, there is no way to tell if there is new information at one of the button sites so all buttons have to be checked each time (problem 3). There are inconsistencies in terminology used throughout the website as described in problems 4 and 5, and three of the buttons were found to lack information relevant to the site (problems 6-8). All eight of these problems are considered to be cosmetic or minor since they did not interfere directly with a user’s ability to perform a task, but may be distracting. The final problem illustrated is simply that the “how to” button on the welcome page needs to be updated. However, this problem was rated a “3,” or a major usability problem because a lack of current help information could interfere with a user’s ability to perform a task (e.g. reading a patient’s record). In fact, the only severity rating of 4 was given to a problem of not being able to access the patient medical records at one point without any explanation.

****FIGURE 3 ABOUT HERE****

****TABLE I ABOUT HERE****

DISCUSSION

This paper illustrated one approach to usability testing during the iterative design of the Web-based human-computer interface for the Spacebridge to Russia telemedicine project. There are many components in effective usability testing. In the case of the Spacebridge project, through bug (or problem) reports, the system designers are also continually getting feedback from all those involved with the project whether their backgrounds are medical or technical. However, even a limited heuristic analysis resulted in a significant number of design change recommendations that had not been reported through the bug report channels. In addition, implementing these changes is less disruptive in a restricted access website than a fully deployed system.

There are also limitations of this approach; The domain knowledge and user functionality were not tested through the heuristic analysis. For example, the website allows clinicians to prepare a case using a standard protocol, including text, data, video, still images (e.g. radiology, pathology) and audio from a desktop and make it available to clinicians world-wide for consultations using the Internet. The ability of the user to prepare a case using the full capabilities of the Spacebridge to Russia website (i.e. the Mbone multicasting function, live video transmission to multiple workstations, or whiteboard function) was also not tested using our method. However, studies in parallel to ours are testing functionality of web site [6].

Extending the method of heuristic evaluation has substantial promise. It has been reported that five evaluators made up of human-interface *experts* as well as actual system *users* can find approximately 75% of the problems in an interface [3]. Full usability assessment would include not only further heuristic evaluation and user-testing, but also it would include addressing

multi-cultural issues involved in interacting with the website to maximize international participation.

Finally, Lessons learned in this testbed will help foster new ideas and approaches for conducting telemedicine and enhancing medical education. These activities are critical for meeting the needs and challenges of addressing medical care regardless of the patient's location.

ACKNOWLEDGMENTS

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Address reprint requests to:

Corinna Lathan, Ph.D.

Biomedical Engineering, Pangborn 104b

Catholic University of America

Washington, DC 20064

202-319-5095 (phone)

202-319-4499 (fax)

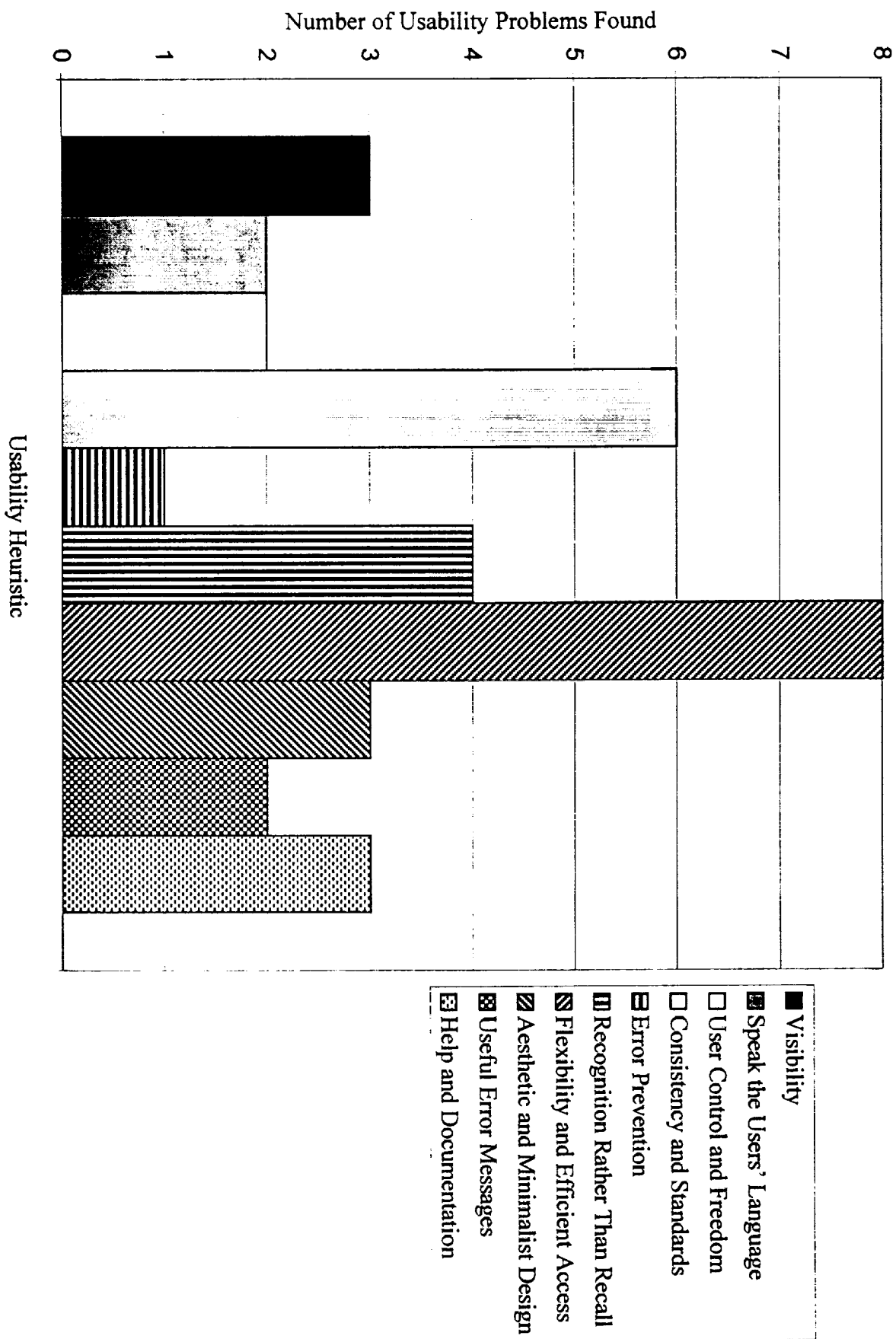
FIGURE LEGENDS

Figure 1: Number of usability problems found per usability heuristic.

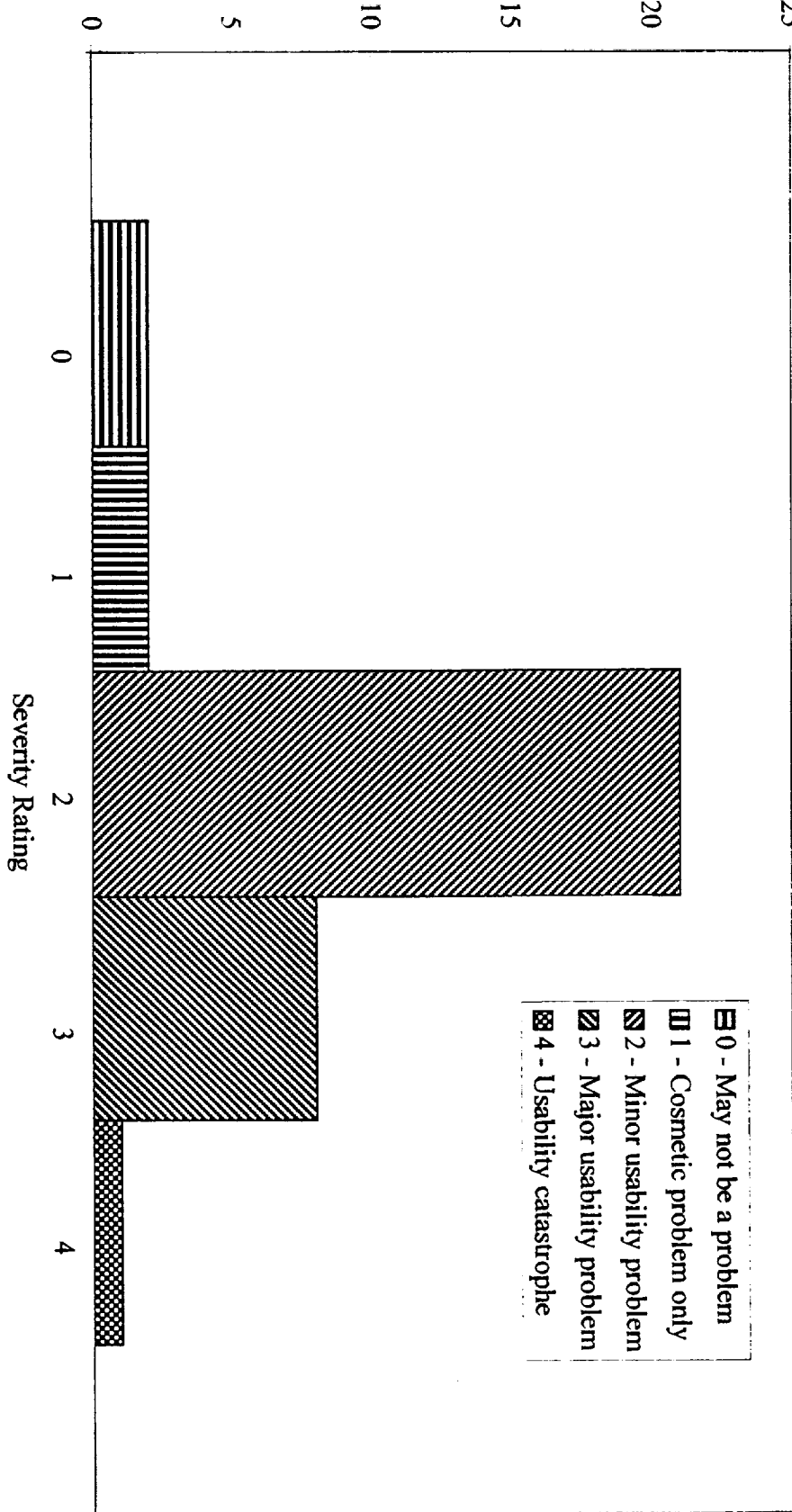
Figure 2: Number of usability problems found per severity rating.

Figure 3: The Spacebridge to Russia Website Welcome Page

Table I: Usability problems found on the Welcome Page.



Number of Probelms Found



- ☐ 0 - May not be a problem
- ▨ 1 - Cosmetic problem only
- ▩ 2 - Minor usability problem
- ▧ 3 - Major usability problem
- ▦ 4 - Usability catastrophe



Final 1996 Telecollaboration Category AWARDS



Powered by: 



Telemedicine Spacebridge to Russia



WARNING: The Telemedicine Spacebridge to Russia server will be unavailable between the hours of 7:00 AM and 7:30 AM EST (12:00 PM and 12:30 PM GMT) due to regularly scheduled maintenance and data backup.

The main content area features a grid of icons for navigation. The central icon is a large image of a medical monitor displaying a patient's vital signs. Surrounding it are smaller icons for 'Patients', 'Calendar', 'What's New', 'Home', 'Documents', 'Bug List', and other site functions.

Spacebridge to Russia Program Manager: Chuck Doorn, NASA Headquarters (202) 358-0821.
Homepage Curator: Spacebridge Webmaster
This page is best viewed with Netscape Navigator 2.0 or higher.
Last updated on Mar 03 14:05:27 GMT1997

Problem	Usability Heuristic	Severity
1. Not clear what's clickable. Just 14 buttons?	Visibility of System Status and Function	1
2. 14 buttons the same size imply the same importance.	Flexibility and Efficient Access	2
3. There is no easy way to tell if there is new information and there are 14 buttons to check.	Help and Documentation	2
4. "People" and "Participants" are used to refer to the same thing.	Consistency and Standards	2
5. "Bug" and "Problem" are used to refer to the same thing.	Consistency and Standards	2
6. Locations listed under "Medical Sites" have nothing to do with this project.	Aesthetic and Minimalist Design	0-1
7. "Awards" button irrelevant. No Spacebridge info there.	Aesthetic and Minimalist Design	0-1
8. "Admin" button doesn't work.	Aesthetic and Minimalist Design	2
9. Update the "how to" information.	Help and Documentation	3

DATA APPENDIX

Problem	Usability Heuristic Violated	Severity Rating
1. Welcome Page: Not clear what's clickable. Just 14 buttons?	Visibility of System Status and Function	1
2. Welcome Page: "People" and "Participants" are used to refer to the same thing	Consistency and Standards	2
3. Welcome Page: 14 buttons same size implying same importance	Organize Information for Flexibility and Efficient Access	2
4. Welcome Page: "Bug" and "Problem" are used to refer to the same thing	Consistency and Standards	2
5. Welcome Page: Location of "Medical Sites" have nothing to do with this project	Aesthetic and Minimalist Design	0-1
6. Welcome Page: "Awards" button irrelevant. No spacebridge info there.	Aesthetic and Minimalist Design	0-1
7. Welcome Page: Is there new info.? (14 buttons to check)	Help and Documentation	2
8. Welcome Page: Update "how to" access multimedia patient data	Help and Documentation	3
9. Server Log: The objectives and capabilities are not clear.	Speak the Users' Language	2
10. Welcome Page: "Admin" button doesn't work	Aesthetic and Minimalist Design	2
11. Is the email shown in the BugID the submitting or answering email?	Speak the Users' Language	1
12. Viewing Patient File: Only one way to view info.	Organize Information for Flexibility and Efficient Access	3
13. Viewing Patient File: Don't realize side bar is there, don't expect it to be there.	Consistency and Standards	2
14. Viewing Patient File: Info broken up into pieces.	Organize Information for Flexibility and Efficient Access	3
15. Viewing Patient File: Size of images isn't stated	Visibility of System Status and Function	2
16. Reliability of site: Patient records weren't always available—can't tell why.	Visibility of System Status and Function	4
17. Correct contact information: Chuck's email	Help and Documentation	3
18. Search-General: Suggestions for keywords given a particular category would be useful.	Visibility of System Status and Function	2

19. Search-Patient: Keyword options for specialty for example	Visibility of System Status and Function	2
20. Search-Participant: Keyword options for timezone for example	Visibility of System Status and Function	2
21. Search-General: The response required for some categories is not obvious (eg. SiteID)	Visibility of System Status and Function	2
22. Search-General: Reset seems to refer to category, but not info. options	Consistency and Standards	2
23. Search-General: takes time to click on all info. options.	Organize Information for Flexibility and Efficient Access	2
24. Search-General: Not clear what the default option will be	Visibility of System Status and Function	2
25. Search-Participants: ORGNAM is used instead of SITEID	Consistency and Standards	2
26. Search Participants: Unclear what searching by Techtype, Medtype, etc. will do (no keywords?)	Visibility of System Status and Function	2
27. Search-Patient: Can't find most recent patients (Category)	Organize Information for Flexibility and Efficient Access	2
28. Search-Patient: Can't show the date the patient was entered (info. Options)	Organize Information for Flexibility and Efficient Access	2
29. Couldn't access any documents. Said "could not login to ftp server"	Visibility of System Status and Function	3
30. Bug report "sort" and "default" not working.	Visibility of System Status and Function	3
31. Patient Registration: "reset" doesn't work if you get to the page after clicking "previous"	Consistency and Standards	3
32. Patient Registration: on page 3, if a finding is typed in—the exam box could be autochecked	Organize Information for Flexibility and Efficient Access	2
33. Patient Registration: in general, switching from mouse to keyboard constantly is awkward	Organize Information for Flexibility and Efficient Access	3
34. Announce page: "clear message" also clears subject field	Consistency and Standards	2

A Web-Based Human Computer Interface For Internet Telemedicine

Corinna E. Lathan*, Dava J. Newman**, Marc Sebrechts***, Charles Doarn****

*Biomedical Engineering, Catholic University of America

**Department of Aeronautics and Astronautics, Massachusetts Institute of Technology

***Department of Psychology, Catholic University of America

****Aerospace Medicine Division, Office of Life and Microgravity Sciences, NASA Headquarters

Abstract

Despite the exponential growth in the number of telemedicine projects and systems, relatively little attention has been paid to the human factors issues associated with such systems. Particularly, no guidelines exist to assist in the development of human-computer interfaces, associated with telemedicine systems, that address the human factors issues of human-computer interaction (HCI) and interface design. HCI is a growing field with the recognition that the human-technology interface is the key to optimizing human performance. Therefore, NASA has supported this effort to apply HCI design principles to the field of telemedicine. There are several efforts underway at NASA to develop telemedicine systems for use in addressing medical care issues in unique environments where health care providers may have limited access to medical facilities. In particular, the web/videoconferencing integrated interface for the Spacebridge to Russia project will be used in this paper to illustrate the principles of good interface design in general and as related to telemedicine systems. Three principles will be addressed: 1) user-centered design 2) modelling the human processor and 3) task and constraint-oriented design, i.e. What is unique to interface design for telemedicine systems.

The American Telemedicine Association -- Panel on Human Factors
Friday, April 4, 1997
4:00 PM - 6:00 PM

Human factors issues have received relatively little attention as the telemedicine field has grown. The integration of the technological and human components has seldom been evaluated in a systematic way or discussed within the broader context of the health care delivery system. This panel presentation will include several perspectives on human factors issues.

Part 1: Human Factors: System Design Issues in Telemedicine

Corinna E. Lathan, Ph.D. (Panel Chair), Catholic University of America, Washington, DC.

"Human Computer Interface Design Principles for Web-Based Telemedicine Systems"

Dr. Lathan is an Assistant Professor of Biomedical Engineering and has worked with NASA on several projects including evaluating a web-based telemedicine system.

Deborah P. Birkmire, Ph.D., Tripler Army Medical Center, Honolulu, HI.

"Human Factors Issues in the Design and Usability of Telemedicine Systems"

Dr. Birkmire is a research psychologist currently assigned to the Tripler Army Medical Center where she has established a human factors usability laboratory specifically dedicated to the evaluation of telemedicine systems.

Marilyn Sue Bogner, Ph.D., Institute for the Study of Medical Error, Bethesda, MD

"Human Error in Home Health Care Medical Devices"

Dr. Bogner is a human factors psychologist involved in incident analysis and research on factors in the system in which health care is provided that impact on the outcome of that care.

Part 2: Human Factors: Communication Issues in Telemedicine

Rufus Sessions, Ph.D. Walter Reed Army Medical Center, Washington, DC.

"Behavior Analysis Approach to Human Factors in Telemedicine"

Dr. Sessions is currently serving a Tricare Region 1 Liaison for the U.S. Army Medical Research and Materiel Command, Medical Advanced Technologies Management Office (MATMO), working in the area of telemedicine implementations in clinical settings.

Gary C. Doolittle, MD, University of Kansas Medical Center, Lenexa, KS.

"The Communicative Dynamics of Talking to a Doctor on TV"

Dr. Doolittle is an Assistant Professor in the Dept. of Internal Medicine and the Medical Director of Telemedicine Services.

Ann Temkin, M.A., A.C.S.W., Shepherd Center, Atlanta, GA.

"Telehomecare services: Unexpected benefits and challenges of entering the real world"

Ms. Temkin manages the Telemedicine Program at Shepherd Center in Atlanta and has expertise in telerehabilitation systems which make it possible to provide services to persons with catastrophic injuries in their homes and local communities.

LATHAN: The integration of the technological and human components has seldom been evaluated in a systematic way or discussed within the broader context of the health care delivery system. In addition, as the user population expands to include remote and under-served populations that will include non-health professionals, user performance will need to be evaluated in light of many different objectives. In particular, no guidelines exist to assist in the development of human-machine interfaces, associated with telemedicine systems, that address the human factors issues of human-computer interaction (HCI) and interface design. HCI is a growing field with the recognition that the human-technology interface is the key to optimizing human performance. Therefore, NASA has supported this effort to apply HCI design principles to the field of telemedicine. In particular, the web/videoconferencing

integrated interface for the Spacebridge to Russia project will be presented to illustrate principles of interface design in general and as related to telemedicine systems. Supported by NASA Grant NAGW-4498

BIRKMIRE: A project to test the feasibility of using "store and forward" technologies for "off-line" teleconsultation between a primary care clinic and a tertiary medical center will be described. The Human Factors Usability Laboratory was established as a fundamental part of the project to assess human factors issues in the design of the system. One of the responsibilities of the Usability Laboratory is to perform usability analyses of commercially available equipment for the proposed telemedicine system. The conceptual framework and methodology that was developed by the Usability Laboratory to perform these evaluations will be described in detail. Specifically, the three components of the methodology, that is, technical acceptability, operational effectiveness, and clinical appropriateness, will be discussed.

BOGNER: Abbreviated hospital stays and the aging population has led to medical care increasingly being provided in the home by lay caregivers. Those caregivers often are given sophisticated equipment with a modicum of training and often incomprehensible instruction manuals. Geographical location as well as constrained resources preclude visits to provide assistance by even semi-trained personnel. Although home medical and rehabilitation equipment use and maintenance error data are virtually non-existent, an extrapolation of error by clinicians using comparable equipment in institutional settings suggests that error is a very real problem not only from its occurrence, but also the fear of making errors by the lay caregiver. Telemedicine capabilities can be used in home health to alleviate some problems with medical devices such as detecting compromised functioning of the device due to lack of cleaning as well as tele-identification and tele-trouble-shooting of operational and maintenance problems. However, extensive work is necessary to develop or modify devices to be amenable to tele-assistance. Examples are provided of medical devices used in home health care, problems in device use reported by clinicians in non-home settings, the relation of the design of those devices to the home use environment, and the characteristics of the user populations. Human factors issues in those examples as well as in home health care in general are identified and discussed.

SESSIONS: This paper will address human factors affecting the successful implementation of telemedicine in clinical environments from the point of view of behavior analysis, that is, focusing on the contingencies controlling behavior in the setting in which telemedicine is practiced. It will be argued that once idealized solutions to the technical problems are achieved, there will remain a set of issues relating to the contingencies under which clinical practitioners operate that will determine the overall utilization of telemedicine technologies. From this point of view, factors that will be discussed include: a) the benefit derived from the utilization of telemedicine by the individual clinician; b) the benefit derived by the institution or practice in which the clinician operates; c) the organizational contingencies that impact on individual performance d) the overall response cost associated with the use of telemedicine procedures e) the clinical outcome; and, f) the role of professional image in the consultative process.

Whitten/DOOLITTLE: Problem: Physician-patient communication has long been a subject of social scientific study. Researchers have documented a plethora of communicative factors ranging from talk time and interruptions to control and body language. However, practicing telemedicine changes many of the interpersonal dynamics between physicians and their patients. For example, research has shown us that a new type of etiquette emerges via interactive video where participants are less likely to interrupt one another. The purpose of this presentation is to outline how telemedicine impacts the communicative behaviors between physicians and their patients, contrast these behaviors with traditional health delivery, and discuss the implications these changes may hold for the changing nature of physician-patient relationships. The presenters bring a unique perspective as one holds a doctorate in communication and the other is a physician practicing telemedicine more than four hours per week.

TEMKIN: A telemedicine project to prevent pressure ulcers among persons with spinal cord injury gave rise to a series of benefits and challenges which were related to human factors rather than to the technology or the service itself. Some of these were anticipated, but many were discovered only through actual experience. These included: the extent to which staff enters the patient's life, including psychosocial and environmental areas; effect on family systems; the intervention's effect on the balance of power between professional and patient; safety concerns; gender related considerations; staff learning curve; commitment and scheduling issues. The presentation will share observations made while working with patients over an extended period of time. Technologically facilitated relationships, their extent, nature and ramifications will be a central theme.

TELEMEDICINE WORKSTATION, EVALUATION AND TECHNOLOGY ASSESSMENT *

Telemedicine programs are being designed and developed for health care providers and patients who have limited access to medical facilities due to location or cost (Arthur D. Little 1992; Grigsby, Sandberg et al. 1994; DeBakey 1995). NASA has an interest in developing telemedicine workstations for medical ground-support for astronauts during U.S./Russian joint spaceflights and future space station activities. In addition, there is a need for telemedicine systems targeting disaster relief and disaster preparedness, and distance learning in the medical community. Section 4.1 defines telemedicine and gives the motivation for studying the user interface. The user scenarios are described in Section 4.2 and the general telemedicine system architectures are shown. Section 4.3 describes NASA Johnson Space Center's Telemedicine Instrumentation Pack (TIP) which is being developed as the medical workstation to be used by the astronauts. Section 4.4 introduces workstation evaluation and Section 4.5 presents a case-study of The New England Medical Center Telemedicine Program (Patterson 1995). The technical background materials are provided in Appendix A.

4.1 Human-machine interface design for telemedicine applications

Telemedicine refers to the use of telecommunications technology to provide medical care to a patient at a distance from the health care provider. The goal of telemedicine is to improve clinical diagnosis, care and efficiency of treatment whether through satellite communications, ISDN links, or hospital-based Picture Archiving and Communication Systems (PACS) (Kohli 1989; Mukhedkar, Laxminarayan et al. 1990; McClelland, Adamson et al. 1995). Telemedicine systems can deliver care to patients anywhere in the world by combining communications technology with medical expertise.

Telemedicine has been shown to improve medical treatment particularly where specific medium to high risk patients can be identified. For example, pre-selected households were installed with ECG equipment (Thorborg and Sjoqvist 1990). Training in the use of the equipment for clinical staff and home users can present a difficulty, but is made up for in a reduction in training times for the first responders since there is an expert monitoring the system remotely.

Until recently, most of the research and applications in the field of telemedicine have focused on the technical feasibility and the political infrastructure (e.g., cost-effectiveness, physician and patient acceptance) (Grigsby, Kaehny et al. 1993; Scott and Neuberger 1995). Increasingly, the user-interface is receiving needed attention as more and more telemedicine workstations are being developed for particular user scenarios or applications (Smith and Mosier 1984; Nakano, Nagai et al. 1990). Study of the human-computer interface can be defined as "the discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them" (McClelland, Adamson et al. 1995).

Human-machine interface design is now considered part of the development process of telemedicine systems. Most interfaces are multimedia-based front-ends to complex networks. Videoconferencing is an example of a commonly integrated media (Turner, Brick et al. 1995).

*Published as Chapter 4 of a 1995 MIT S.M. thesis in Aeronautics and Astronautics, "Sensorimotor Adaptation Of Human Control Strategies: Ramifications For Future Human-Machine Interface Design" by Corinna Lathan.

The interface is critical because many users lack significant experience with the technologies involved. For example, network protocols are complex can require many set-up parameters. The clinician should be isolated from these hardware requirements. Software designers must adopt a user-centered approach which is compatibility with the user's expectations, provides the user with flexibility and control, explicit structure, continuous and informative feedback, error prevention and correction, and on-line help (McClelland, Adamson et al. 1995).

Previous evaluations of telemedicine systems have focuses on general characteristics and not the user-interface specifically (Grigsby, Sandberg et al. 1994; Bashshur 1995). However, lessons learned from past evaluations are applicable here. In his review of telemedicine evaluation, Bashshur (1995) summarized the past telemedicine projects up to the 1970s with three points. 1) The systems were underused and did not fully exploiting the technical capabilities they had. 2) The projects had narrowly defined function and targeted special groups. and 3) Few conclusions were able to be drawn concerning role or effect of telemedicine in the healthcare delivery system. He also observed that client and provider acceptance were high and increased with experience and familiarity of the system.

Bashshur suggests that three conditions be met before an evaluation. 1) The appropriate environments and specific healthcare needs are identified that would be best met through a telemedicine system. 2) The specification of informational requirements necessary for remote diagnosis, treatment, and follow-up as well as for education. and 3) An attempt to exploit to the extent possible the technological and system capabilities that are in place. He then suggests that evaluations must consider these three conditions and evaluate the appropriate contexts, optimal system configurations, and the full range of effects of the telemedicine system whether immediate or delayed, intended or unintended, and direct or indirect.

4.2 Defining the User-Scenarios

The telemedicine system architectures for the user-scenarios are shown in Figures 1-3. There is a continuum in both user medical expertise and system requirements.

4.2.1 *The Primary User Scenario*

To provide medical care for astronauts in support of U.S./Russian joint spaceflights and future space station activities. Figure 1 shows a conceptual model of this user scenario which includes a trained flight surgeon at the ground-based telemedicine workstation and a trained astronaut "patient" in space. The astronaut will be using NASA Johnson Space Center's Telemedicine Instrumentation Pack (TIP). TIP is a portable, small suitcase, containing medical instrumentation and support equipment. The specifications of TIP will be covered in more detail in Section 4.4. The third node of the user scenarios would provide access to medical databases and medical consultants or experts.

4.2.2 *Secondary User Scenarios*

To provide assistance in disaster relief and disaster preparedness (see Figure 2) and to provide opportunities for distance learning and retraining in the medical community (Figure 3).

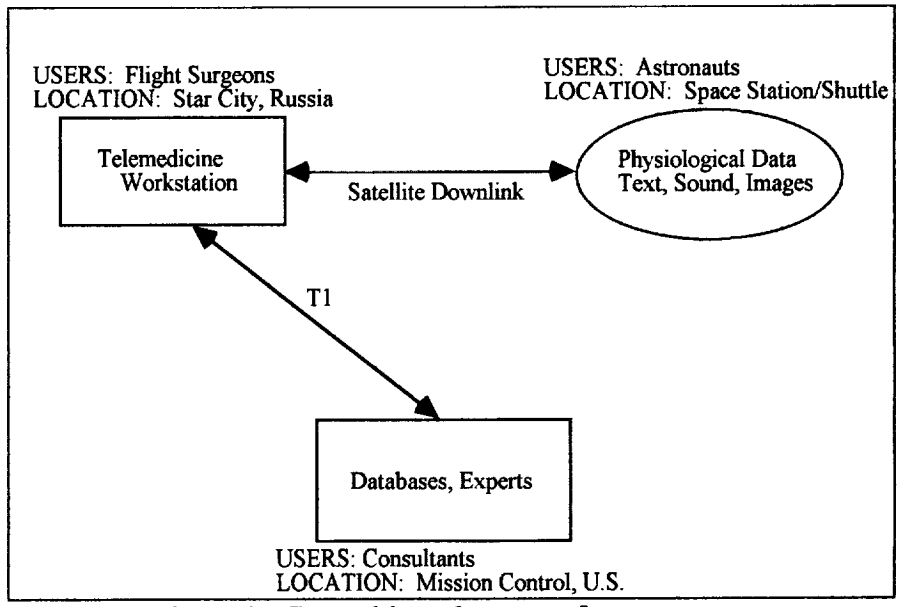


Figure 1: Ground-based support for astronauts

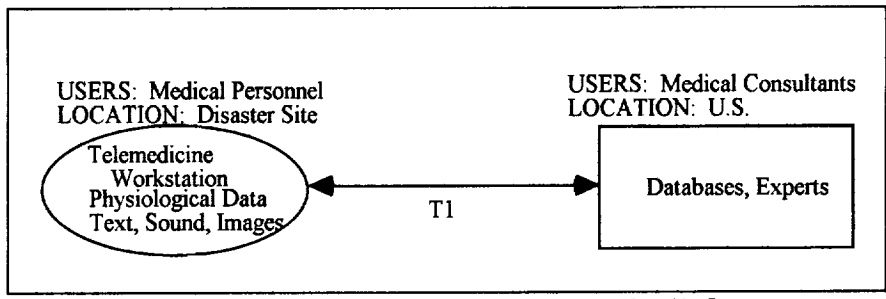


Figure 2: Disaster preparedness and relief.

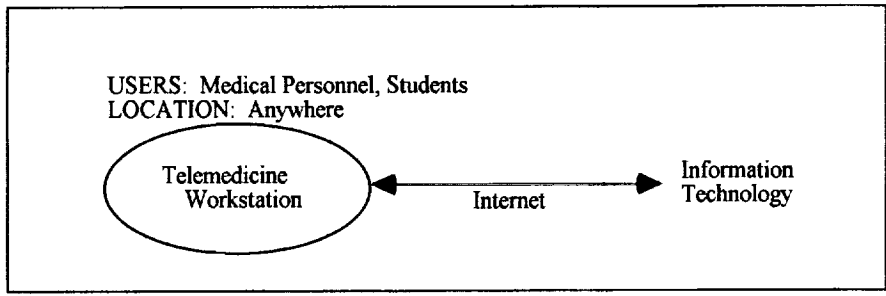


Figure 3: Medical education.

4.3 Telemedicine Instrumentation Pack (TIP)

The Telemedicine Instrumentation Pack (TIP) is being developed by KRUG Life Sciences, a contractor for NASA Johnson Space Center. TIP's purpose is to provide medical instrumentation and support equipment in a portable pack for use by the astronauts on future spaceflights. Video capabilities include eye, ear-nose-throat, skin, and general macro-imaging. Data capabilities include electrocardiogram (ECG) waveforms, heart rate, and blood oxygen saturation. TIP provides audio of the heart, lungs, and bowels. All data obtained can be accessed at serial output ports for transmission to earth. Support equipment includes a flat panel liquid crystal display (LCD), a remote head CCD camera, a light source, and a power supply. The following is a summary of TIP capabilities:

VIDEO: An otoscope and ophthalmoscope provide general exams of the eyes and ears respectively. A macro/zoom lens is used for dermatology examination. A rhino-laryngoscope is used for high quality imaging through a fiber optic cable to image nasal, sinus, and vocal chords. A fundus camera is used for video retinal imaging.

AUDIO: An electronic stethoscope is used for the transmission of heart, lung, and bowel sounds. (A piezoelectric crystal located distally from the earplugs converts sound waves to an electrical signal. The audio out is digitized to get a broader bandwidth than is possible with analog signals).

DATA SUBSYSTEMS: A pulse oximeter is used to determine oxygen saturation and heart rate. An ECG monitor is capable of recording 3- 12 lead electrical activity. Blood pressure is automated. An onboard computer multiplexes the data streams for transmission.

DEVELOPMENT: Potential developments include replaceable instrumentation modules and advanced HMIs. For example, a heads-up display could augment or replace the current flat panel LCD. Technologies that would allow a "hands free" operation are also being evaluated.

TIP will have to handle a variety of medical scenarios. The more preparation that can be done before launch, the better the care of the astronauts. Potential medical scenarios are as follows:

Medical Scenarios

1. Daily physicals/General check-ups
2. Floating particles in the eye
3. Decompression sickness
4. Cuts/abrasions
5. Gastrointestinal disorders (constipation, diarrhea)
6. Toxic spills
7. Heart attack

Each of the medical scenarios will involve varying levels of intervention from a ground-based flight surgeon. For example, data from daily physicals would be continually down-loaded for evaluation. A small particle in the eye could be dealt with completely independent from ground-based intervention whereas a heart attack would involve two-way data transmissions of physiological data and intervention.

4.4 Workstation Evaluation

Telemedicine is being conducted in hospitals and universities all around the world, using a wide variety of equipment. This reports concentrates primarily upon general workstations, suitable to fill many different roles. Technical background for the components of a telemedicine workstation is provided in Appendix A*; Platform, display, input devices, and networking components are summarized. The role a general workstation can fill is three-fold, with each tier increasing in complexity:

Tele-education/Reference: Essentially the system provides access to clinical data and images, as well as hypertext images and diagnostic aids. The system may be connected, either by modem or network to a LAN or the Internet, to facilitate communication, but this aspect of the project is secondary. Such a system has little to distinguish it from a conventional workstation, save its dedicated purpose.

Portable Service Provider: This system, adds teleconferencing capability to the previous workstation. Images and clinical data may be sent from a hospital, local or remote to the station, and the reverse. Such a system is equipped with some fairly simple image capture hardware, and provides for either voice or text communication with a remote sight.

Full Workstation: This is a system designed to be used at a stationary site. Separate hardware is available for videoconferencing and image capture, links are provided for a variety of different modes of communication, and the system provides integrated control and access to remote cameras, instruments, and patient records.

Table 1 shows a compiled list of existing vendors and universities whose products and projects are being used.

Table 1: List of Vendors and Universities

3M Medical Imaging Systems	Dupont Medical Products
A&S Communication	Telemedicine Alliance of Health Organizations
AAC	Boise State University Center for Health Policy
AC&E Limited	University of Arkansas
Acuity Imaging Inc.	National Laboratory for the Study of Rural Telemedicine
ADCOM Electronics	DeJarnette
Agfa Division Technical Imaging Sys	DR Systems
American Telecare, Inc.	Corabi
Analogic	
Andries Tek	University of Washington, ICSL
Apollo Software	Lockheed Martin
CAE-Link	Texas TelemedicineProject
CPI/MicroAge	University of Texas Medical Branch
DataView Imaging	Gammex RMI
EMED	GE Medical Systems
HealthCom	Medical Image Management, Inc.
Heraeus Surgical	Los Alamos NL (Sunrise)

* Thanks to UROP Michael Metzger for assistance with compiling the technical overview and video demonstration.

ICON Medical Systems	ICE Communications, Inc.
Loral Medical Imaging Systems	J.D. Technical Services/RediVu
md/tv	Applied Science Associates, Inc.
Medweb	Cyberspace Telemedical Office
Olicon Imaging Systems	Line Imaging Systems
Peirce-Phelps	New England College of Medicine
Radman	Magnetic Research, Inc.
Roche Image Analysis Systems	AT&T (Picasso)
Rstar	CompuMed
Scottcare Corp	University of Pisa (IMPHONE)
Shure	Mountaineer Doctor Television
Specialized Home Care, Inc.	BioPac
Stryker Endoscopy	Georgetown Medical Center
Turcan-Wingard Associates	PictureTel
United Medical Network	High Plains Rural Health Network, and
Video Dynamics	Decisions Systems Group (Brigham and Women's Hospital and Harvard Medical School)

The best workstation depends on the user's needs. All of the workstations evaluated will be entered into a database that will be part of an on-line search engine. The user defines her telemedicine workstation needs via a checklist interface. The system will search for the workstations that fulfill those needs. Each system will be described in a standardized format, shown as follows:

System Name:	
Vendor:	
Contact Information:	
Pricing:	May not be applicable for academic systems
Processor Type:	Will also include benchmarks to evaluate the relative capabilities of different families of processor.
Display:	Resolution, color depth, and screen size.
Communications:	Communication protocols which are supported transparently, as well as the possible data transmission rates, and any requirements for the link between computers.
Interface:	Both hardware (keyboard, touch screen, voice) and software (access to remote databases, authoring tools, Graphical interfaces, etc.)
Video capabilities:	Full motion video (and sound).
Expansion:	Options which may be purchased, either through the vendor or, for open architecture systems, supported third parties.
Role:	The role the system was designed to satisfy. Possibilities include image transmission and archiving, teleradiology, videoconferencing, general, and others.

Finally, there will be a short paragraph describing any other relevant or unusual features of the workstation in question. For workstations which have been studied or had their capabilities analyzed in the literature, the relevant references will also be reported.

Three workstation evaluations are presented here as representative types of workstations in use that will be incorporated into the database. Workstation A, the Lockheed Martin Telemedicine Workstation, is a general purpose workstation whereas Workstation B, the MediaStation 5000, is a special-purpose workstation utilizing third-party technology. Workstation C, the CADx, is a high-end, pre-packaged, special purpose workstation.

A. General Purpose Workstation

System Name: Telemedicine Workstation
Vendor: Lockheed Martin
Contact Information: James P. McCormick
Project Manager, Medical Integration
Lockheed Martin Information Systems
12506 Lake Underhill Road, MP830
Orlando, FL 32825-6401
Phone: 407 826-6401
Fax: 407 826-6539

Pricing:
Processor Type: Pentium, 66 MHz
Display: 17" 1280x1024 color monitor
Communications: Codec 384 Kbps video channel, V.35, 802.3, T1, ISDN
LAN: Ethernet, Super Ethernet, ATM FDDI
Interface: Touch screen, keyboard, mouse,
Video capabilities: 384 Kbps video
Expansion: Expanded video capabilities, remotely controlled cameras, NTSC instrumentation package (Otoscope, Ophthalmoscope, Dermoscope, etc.), Super VHS VCR, Full Motion Video display, capture, store and forward.

Role: Integrated, general purpose workstation.

The Lockheed Martin Telemedicine Workstation is a flexible, open architecture general purpose workstation. It is designed to allow point to point videoconferencing across a 384 Kbps phone link, and can take advantage of the higher bandwidth of a dedicated T1 line, or a satellite link with additional hardware. The software is the company md/tv's HouseCall™, a Microsoft Windows based package. The system allows access and manipulation of 4GL multimedia databases, control of remote cameras, electronic record keeping, integrated multimedia and videoconferencing capabilities, and annotation of images. The primary interface is icon driven, by use of the touchscreen or the mouse.

B. Special Purpose Workstation: Using 3rd Party Technology

System Name:	MediaStation 5000
Vendor:	University of Washington Image Computing Systems Laboratory
Contact Information:	
Pricing:	
Processor Type:	Texas Instruments TMS320C80 2 billion operations per second
Display:	1280x1024 capable
Communications:	NA
Interface:	NA
Video capabilities:	MPEG-1 compression of 352x240 pixel video @ 30 Hz
Expansion:	NA
Role:	Advanced Digital Signal Processing

The MediaStation 5000 is a plug in board for a Local bus or PCI PC which greatly enhances its signal processing capabilities. The board can perform real time MPEG-1 compression and decompression at 30 framed a second on SIF video, with 16 bit 44 kHz audio. The board is programmable and can also be used for compression, two and three dimensional image processing and graphics, and other DSP intensive tasks. Projects incorporating the board include the GSP9 a general purpose telemedicine workstation (using the ITU H.320 standard for videoconferencing), the GSP7 a real-time optical imaging workstation, and the GSP8 a tool for visualization and analysis of three dimensional ultrasonic angiographs.

C. Special Purpose Workstation: High-End Pre-Packaged

System Name:	CADx
Vendor:	Georgetown Medical Center (ISIS Center), Cray Research
Contact Information:	
Pricing:	
Processor Type:	Cray J916
Display:	2048 x 2048
Communications:	Still under development, to support HIPPI, ATM and other high speed communications standards
Interface:	Non-standard
Video capabilities:	none
Expansion:	under development
Role:	Filmless radiology

The CADx software and system is an attempt to bring about filmless radiology. The initial goal is to achieve this within the hospital itself, while designing the system for easy transmission and receipt of images to allow a transition to a telemedicine framework. The system has two primary functions. First it will receive, store and catalog all X-rays replacing conventional film with direct digital capture and computer display. The design goal is for the system to display the image in a fraction of a second, rather than the several seconds a high end workstation would require. Second, the system aids with the analysis of the image. Currently, the analysis is restricted to finding microcalcifications in mammography data in order to detect breast cancer. The system can detect microcalcifications in the range of 100-200 microns, about the width of a human hair.

The next phase of the project is to expand analysis to other ailments, and areas of the body. In addition, Georgetown Medical Center is being connected with area hospitals, allowing them to transmit their mammography data for automatic analysis.

4.5 Case Study: The New England Medical Center Telemedicine Program

As a technology designed and developed to provide a tool to health care providers in unique situations, the human/machine interfaces should also be evaluated. The interface chosen will have a direct relationship to the health care providers' performance. Human performance during telemedicine activities will be crucial in determining the difference between use and nonuse of a system and the difference between diagnosis and misdiagnosis. Determining the important components of the human-computer interface for each telemedicine system will have ramifications for the work-station design, the needed computer literacy, and level of technology used. A related component to operator performance is the amount and type of training needed for effective use of the telemedicine workstation. Therefore, training duration and learning-curve effects should also be considered in workstation design.

The telemedicine system chosen for our case study is that developed by the Medical Image Management Company for the New England Medical Center Telemedicine Program. John Patterson, Vice President and CIO, outlined the NEMC program at the Telemedicine 2000 conference in Lake Tahoe, CA, in June, 1995. He summarized the NEMC Telemedicine Program as being clinically driven, affordable, requiring low bandwidth (less than anticipated), and using third party product development, and an "open" architecture environment (i.e., the hardware is independent of the server). A summary of the workstation is shown on the following page as Workstation D.

Amidst national focus on downsizing health care systems, there is a drive to increase the efficiency of health delivery systems, to achieve high quality, low cost care. Some of the driving forces behind the development of the NEMC telemedicine applications are 1) the maintenance and expansion of traditional referral relationships, 2) the drive to expand services; provide national and international diagnosis and consultation services, 3) reduce the cost of health care 4) increase the access and quality of medical care for rural, distant, and underserved populations

NEMC has several deployed telemedicine programs in Massachusetts. Telepsychiatry was initiated for nursing home geriatric populations with medical rounds using 384 Kb links. Second opinion consultations on fetal ultrasound monitoring and care management were obtained using store and forward data transmitted on 256 Kb lines. Ophthalmologic consultation, diagnosis and care management and angiogram consultation and care management cases were also observed.

D. Open Architecture Workstation Used By NEMC Telemedicine Program

System Name:	N/A (see On-Call interface software)
Vendor:	Medical Image Management
Contact Information.:	815 Montgomery Street Fall River MA, 02720 Phone: 508-672-2931 Fax: 508-672-5008
Pricing:	\$15,000-\$20,000
Processor:	Intel 486
Display:	any (1024x768x256 and above likely)
Communications:	ISDN, 10baseT Ethernet, fiber optic capability
Interface:	Windows 3.1 based,
Video capabilities:	PictureTel Full motion video, PCS-100
Expansion:	Cardiac angiogram, ophthalmology, obstetric ultrasound, home health consultation, pediatric cardiology ultrasound, comprehensive patient consultation, echo cardiology, medical image acquisition, management, archiving
Role:	General Purpose

Medical Image Management has produced a workstation based almost on open standards. The system software and hardware can be added to an existing PC running Windows or a Macintosh, or a PC can be purchased along with the system. Using On-Call software by The Method Factory, the workstation allows access to on-line databases, lets the physician develop customized forms for use by the patient or secondary care giver, and allows for easy control of remote cameras and instrumentation.

Two major telemedicine systems are currently being deployed, one in Latin America and one in support of Pediatric Leukemia patients in Massachusetts. The Latin America project is a comprehensive telemedicine system for a 400,000 member managed care population in Buenos Aires. This system is a SmallTalk shell around the client. This system architecture is shown in Figure 4. The second system is a comprehensive home health system incorporating videoconferencing, medical appliances, bi-directional home to hospital results messaging, expert system which provides diagnosis and educational services. One of the goals of this system is to prevent rehospitalization which can be costly as well as traumatic. Dr. Larry Wolf at the NEMC Floating Hospital for Children is testing this system with Pediatric Leukemia patients.

Future plans of the NEMC Telemedicine Program include expanding the applications of these comprehensive clinical "workstations" to nursing homes, community health centers, correctional populations, and psychiatric hospitals. These workstations would also include care management, outcomes and productivity improvements.

4.5.1 *Communication Links: ISDN*

Integrated Services Digital Network (ISDN) is a set of communication standards which allow a single wire or optical fiber to carry voice, digital network services, and video. ISDN is intended to replace the current Public Switched Telephone Network, and supports both old copper wire and switching systems and newer fiber optic systems. ISDN accomplishes this by defining several different types of channels. ISDN also provides additional flexibility by providing users with access to more than one channel at a time for data transmission.

B Channel: This is a 64 kbps channel which carries customer information, or provides a connection based or connectionless link.

D Channel: This is an access channel carrying control or signaling information, or providing a data link.

Basic Rate Interface: The BRI consists of two B and one D channels. This channel can carry two simultaneous voice and one "data" communication, or provide a communication link with and bandwidth of 128 kbps.

Primary Rate Interface: In the United States, this consists of 23 B channels and one 64 Kbps D channel, or a 23B+D connection. This provides a total bandwidth of 1.544 MBps, which corresponds to that of a T-1 trunk, and provides service equivalent to DS-1.

Broadband standards for ISDN have also been designed, which will rely upon implementing ISDN on top of the SONET protocol. Channel classification of the different services is provided below.

{T-0}	64 Kbps
{T-1}	1.544 Mbps
{T-1C}	3.15 Mbps
{T-2}	6.31 Mbps
{T-3}	44.736 Mbps
{T-4}	274.176 Mbps

At present, not all areas of the United States have access to ISDN services, and those areas that do often only have T-0 and T-1 capability.

4.5.2 *User Interface*

User interfaces employing full-motion video and other such multimedia information require broadband networks as well as advanced human interface design. Broadband networks such as ISDN have been used for telemedicine applications (McClelland, Adamson et al. 1995) as well as Picture Archiving Communication Systems (PACS) (Kohli 1989). With increased bandwidth and graphical user interfaces, more attention has been paid to the interface design and in fact, an ISDN terminal adapter was developed (Nakano, Nagai et al. 1990) with a friendly interface based on proposed guidelines (Smith and Mosier 1984).

The NEMC Telemedicine Program in collaboration with The Method Factory, Inc. have developed a user interface, "On-Call". On call is an object-oriented software developed to provide a flexible interface for health care providers and their patients. On-call has two modes. One mode is the author's mode in which a health care provider could construct a multimedia checklist. A library of multimedia interface buttons are clearly marked on the screen which can be used to create a hierarchical patient instruction software. Depending on patient answers, a pre-taped instructional video may be triggered, further written information may be requested, or

a video-conference with the doctor may be initiated. The author of the checklist can set the severity index of all answers so that if a certain threshold is reached a videoconferencing call may also automatically be initiated. A "constellation," linking symptoms can also be created that can then elicit a pre-programmed response. In the patient mode, a seamless program appears that explains and instructs while keeping track of all the responses. All patient records are updated both on the On-call workstation as well as at the hospital. On-call will be evaluated during the Pediatric leukemia project as well as the Argentina project.

4.5.3 Cost

The NEMC Telemedicine Program believes that it can reduce costs and liability while improving access to and quality of care for state and federally funded mental health, community health center, nursing home and correctional populations. One of the advantages of the NEMC Telemedicine Program's approach is that individual doctors or health-care providers can make affordable commitments to a telemedicine system without an entire institution committing costly resources to developing a program. The commitment to telemedicine services is a segmented decision process that may be only \$700/month to support. Bandwidth costs are also low since ISDN can be provided at \$42/month.

The original investment of a baseline system supporting videoconferencing, ultrasound, and echocardiography is less than 14,000 as shown in Table 2.

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APPENDIX A: TECHNICAL BACKGROUND

1.0 Telecommunication-Based Levels of Telemedicine

Just as there are many different aspects of treating a patient, from surgical intervention to accurate record keeping, so there are many activities which fall under the umbrella of telemedicine. These can be broken down roughly in terms of the degree of technical sophistication required to perform each activity.

Text Data Transmission : This is the simplest level of telemedicine. It simply involves passing a (secure) message from one computer to another, something which happens millions of times each day. This capability can be very easily and inexpensively achieved.

Image Transmission : Image transmission require greater communications bandwidth and processing power. The image must be compressed, transmitted, decompressed, and displayed at the remote location. This requires a processor of sufficient power to handle the compression and decompression on each end, a link quick enough so that the image can be transmitted in a reasonable amount of time, and a screen with sufficient resolution to display the resultant image.

Tele-Consultation: In Tele-Consultation, there is real-time interaction between the doctor and the patient. This could involve transmission of telemetry, a videoconferencing link, rapid transmission of images, or all of the above. The connection is not sufficient for the doctor to serve as the primary diagnostician, but may be used for second opinions, and to screen patients whose condition is not time-critical.

Tele-Presence: Tele-Presence requires a higher degree of control than Tele-consultation. Images and data is sufficient for the physician to be the primary diagnostician, and medical imaging, visual data and audio data as well as instrument telemetry are all available. Skilled assistance on the other end of the link need not be that of a physician.

Remote Intervention : This involves physical interaction with the remote patient. A robust, very high bandwidth link, specialized three dimensional pointing devices, teleoperated waldos, and a great deal of computational power are all required to bring this about. For surgery, a full virtual reality environment, complete with tactile feedback would be required. Although some research is being conducted in these areas, a general affordable workstation with these capabilities is still many years away.

2.0 Choice of Platform

There are three main platforms to choose from in the U.S, A UNIX RISC system, an Intel system, or a Apple Macintosh based system. Each system has its own advantages and disadvantages, especially when speaking of the Intel and UNIX systems which may vary considerably from vendor to vendor. The UNIX system has some advantages in robustness, the DOS in cost, the Macintosh in ease of maintenance and use, but all can perform the same basic tasks. The designer of the particular system must decide which aspects of the system are to be most important, and decide accordingly.

UNIX systems: In general, UNIX systems are the most technically sophisticated of the three choices. Versions of the UNIX operating system exist for many high end RISC processors. Between UNIX, the operating system, and Xwindows, the interface which users generally see, the details of the underlying hardware is abstracted away. As a result it is generally much easier to port a program from one UNIX system to another than it would be to port that same program to a Windows system or a Macintosh. Ideally, this prevents dependency on one system vendor for hardware. In actuality, the function of the software in question will settle portability issues. For example, a program which is primarily devoted to image transmission across a network, or file manipulation is likely to be very portable. However, a program which relies upon a digital image capture board which is only produced by one particular manufacturer will still require the board no matter how portable the rest of the system is.

In addition to portability, cutting edge UNIX systems tend to be faster than cutting edge Intel or Macintosh systems. This is largely because of the portable nature of UNIX. Since UNIX code is generally distributed in the form of source code, each time a new processor is developed, the programs used can be recompiled and re-optimized to handle even radical redesign. Intel's x086 series, by contrast must maintain backward compatibility with chips produced over a decade ago. In a sense, each processor must be able to do everything its predecessors could, as well as the new tricks that make it particularly speedy.

UNIX as an operating system also tends to be less susceptible to system crashes than the Macintosh or the DOS/Windows platform. It is an operating system that networks easily, as most of the theory of modern networking was worked out on UNIX platforms of one kind or another.

However, UNIX platforms tend to be expensive, requiring large amounts of RAM (16MB+) and sizable hard drives to deliver acceptable performance. In order to keep systems up and running, experienced system administrators are required, and adding hardware or software is also a job for an expert. UNIX systems tend to be less accessible to a novice, and software for them tends to be more in keeping with an academic environment than a business one.

SUMMARY

PROS

Good portability
Robust, crash resistance systems
High performance processors

CONS

Expensive
Not a large business market
Often require technical sophistication

INTEL/DOS/WINDOWS: The greatest single advantage the Intel platform has is its enormous size. Far more x086 based computers are sold than all other kinds combined. This keeps hardware and software costs low, and provides for rapid turnover in the marketplace. The development tools for this platform are both prolific and excellent, and there are a huge number of choices for any particular piece of hardware or software. This keeps prices low, and gives the user a great deal of flexibility, but also means that a great deal of information must often be sifted through to obtain the needed system.

There are essentially four operating systems available for an Intel PC. The first is DOS. A barebones DOS system is almost certainly inadequate for any workstation that must deal with images, as DOS programs are effectively limited to using only the lower 640Kb of system memory. This is obviously impractical when dealing with images that may be many times this size. Windows provides a uniform graphic interface, access to a system's full memory, and a level of hardware abstraction. Windows is widespread, and supports a huge amount of hardware

and software, but it is technically less sophisticated than UNIX, and more prone to crash. Then there are both OS/2 and Windows NT. Both systems are on a par with UNIX for technical sophistication, robustness, and crash protection. Unfortunately both operating systems are comparatively new, and have a relatively small base of supported hardware and software.

SUMMARY

PROS

Inexpensive
Well-known
Excellent development tools
Wide choice of vendors

CONS

Operating system unsophisticated
Possibility hardware/software
Unsupported
Knowledge needed to separate good
vendors from bad

Apple Macintosh: The Macintosh's great advantage, is that at present, it is a single vendor computer. This means that software and hardware setup and configuration is very simple. The Macintosh also pioneered the Graphic User Interface, and Macintosh software tends to possess a consistent look and feel.

The new Mac's are based on the PowerPc series of microchips, the result of a collaboration between Apple, IBM, and Motorola. These are Risc chips, and in general provide the best computational power at a given cost of any of the system mentioned. For a complete computer however, the competition and larger sales of Intel based systems tend to make them slightly cheaper.

The Macintosh operating system is in a state of flux at present. The current version is probably on par with a DOS/Windows system -- more prone to crash than a UNIX system, but still sophisticated enough for intense use. The next version should be more powerful, and on a level of sophistication equal to that of a UNIX system, but as of yet it does not exist.

SUMMARY

PROS

Easy set up, maintenance, use
of vendors
Strong development environment

CONS

Small user base

3.0 Display

Monitors : Most computer monitors today can display a wide range of resolutions and color depths from 640x480 pixel 4 bit (16 color) VGA to 1024x768 24 bit (true color). The difficulty arises again in the wide range of uses a generalized workstation must be put to. Ordinary television is of much lower resolution than virtually all computer monitors, but a television program achieves much greater apparent resolution by being able to zoom in and zoom out at will. The difficulty lies in the fact that there are two conflicting standards at work. A doctor involved in a face to face consultation with a patient can easily accept television quality video, but she wants the image to be large, not confined to a tiny corner of the computer screen, in order to foster the illusion that the patient is talking to a doctor, not a computer. By contrast, a doctor who must examine an X-ray or the results of an MRI scan will want a display with the finest resolution. Currently existing display technology is sufficient for X-ray images (2.5k by 2k by 12 bit gray scale) but other applications such as mammography require a greater resolution than has been attained by any commercially available monitor.

For applications in which a 1280x1024 true color image is sufficient, monitor size also becomes an issue. Such images can be displayed on a monitor as small as 14 inches (with a still smaller view area) or as large as 21 inches (or larger). In general, a greater image size means less eye-strain, and easier use over the long run, but adds greatly to the cost and weight of the system. In addition, large monitors are far more prone to exhibit minor imperfections which distort the image in one way or another, and as a result must be chosen far more carefully.

Image Capture: Every image that is viewed on a computer screen must be digitized and entered into the computer somehow. There are three main ways of accomplishing this.

Flatbed Scanners: Flatbed scanners are dedicated devices which scan a document or a radiology film at a specified resolution. Inexpensive scanners with image sizes of 1280x1024 and 300 dot per inch resolution are fairly common. More powerful and expensive scanners also exist which are sufficient to input 2.5k by 2k radiology film at 8 bit per pixel gray scale.

Video Cameras: A video camera may display a field of view, or it may be mounted above a light board in order to read documents or films. The best video camera are limited to a resolution of approximately 1280x1024 pixels.

Direct Digital Capture: For certain forms of medical imaging, such as MRI scans and CT scans, the image may never be recorded on a film, but may be directly recorded as digital data. In this case, displaying the data on a computer is largely a matter of knowing how the information is coded. many forms of radiology are moving toward direct digital captures, and away from films.

Real time video: Real time, NTSC quality video requires a communication bandwidth of 90 Mbs/second. There are a large number of compression schemes which deliver video at various bandwidths, as well as more general compression applicable to any series of images, such as MPEG. Real time is generally defined as 30 frames a second.

3-d Models: As telemedicine grows more sophisticated, and 3 dimensional images are transmitted, display becomes quite a different prospect. While the previous problems of resolution and bandwidth still exist, computational resources become equally important. A great deal of computational power is required to display, at an arbitrary angle, the a two dimensional representation of a three dimensional image. There are a number of systems (notably SGI) and add on boards which can perform these calculations, thus removing that burden from the CPU. These will become increasingly important as more complex information is translated. It is unlikely, however, that they will play any role in a general workstation in the immediate future.

Stereoscopic Display: A stereoscopic display is one which presents a slightly different image to each eye, creating a sensation of depth. These displays fall into to broad categories. The first involves a conventional computer monitor, and a set of dedicated glasses. By opaquing each eye on the glasses many times each second and carefully controlling the image on the monitor, the illusion of depth results. The second method of achieving this effect is to place two, very small monitors in a set of glasses, and have each image differ slightly. At present, stereoscopic displays are not cost-effective for most applications.

4.0 Input Devices

Keyboard: While the keyboard is the usual choice for entering large quantities of textual or numeric data, it does have several disadvantages. An inexperienced user can be extremely slow, and its use is in no way intuitive in a graphical environment. Nevertheless it is probably still the best, and certainly the most popular way to input text into a computer, and an indispensable part of most systems.

Mouse/Trackball: What the keyboard is to text, the mouse is to a display screen. Mice combined with a uniform display allow a user to easily select from a broad list of options, designate areas of interest, and navigate an onscreen "pushbutton" interface. Mice generally need a fairly large (1.5' x 1.5') flat area in order to be used, and a fair amount of elbow room. Trackballs, which require less room are preferred by some, and can be made an integral element of the keyboard.

Pen based system : A pen based computer generally looks much like a child's Etch a Sketch, minus the knobs. An imperceptible grid built into the display surface picks up the pressure of the stylus, and translates the motions of the pen into actions. Such systems tend to be very portable, and extremely appropriate when used as checklists, or for other purposes not involving large amount of data entry. Most pen based systems also have strong handwriting recognition capabilities, although these of course require that the person write legibly. Although a complete novice could use a pen based system more quickly than a keyboard system, after only a few hours of practice, most people can type more quickly and accurately than they could write with such a system. The portability is perhaps the most important aspect of these systems.

Touch Screen: Similar technology to the pen based system, only incorporating a stand alone monitor, rather than a pad and stylus. Touchscreens can quickly used with no training, but they tend to be very limited in their ability to input information. Good for choosing among a limited number of options, but probably not a viable choice for a user of any experience. One obvious downside to the touchscreen is the inevitable fingerprints which collect on the display area as it is used.

Speech Recognition : Speech recognition in a fairly limited form is already broadly available. On the positive side, it provides a very natural, hands-free way to communicate with the computer. On the down side, current systems can tend to be finicky about certain users, or the level of background noise. They require moderate computational power, and require users to speak in a fairly small vocabulary of clearly dictated commands. While attempts to decode both continuous speech and full sentences are underway, both place unreasonable demands on the processing power of the computer, and even so are not fully satisfactory. Speech recognition could be ideal for manipulation of images during surgery, or when the hands are otherwise occupied, and the command set is small (larger, smaller, bright, next, etc.). A system which could accept the command "bring up Mrs. McGillicuddy's records" might even be possible, although the backup keyboard system would probably be more efficient.

5.0 Networking

One of the central issues in designing a telemedicine workstation is determining how it will transmit and receive the necessary information. The speed of the link between the two computers determines absolutely the amount of information that can pass between them.

In order for the information to be stored in a computer, and then transmitted, it must be converted from analog to digital form. The way this is done depends on the type of data involved, but follows the same general principles. Essentially, the analog data is sampled, its values are tested at regular intervals and recorded. The more accurately the values can be stored, and the more frequent the sampling, the more closely the digital information reproduces the analog original. If a low sampling rate and value range is chosen, information is likely to be lost. If the sampling rate and accuracy equals or exceeds the precision of the instrument which captured the data originally, then practically no information is lost.

A telemedicine workstation has four basic classes of data it must be able to transmit and receive. These can be thought of as static, one, two and three dimensional data files.

Static data: Files quite simply do not change. These would include information such as the patient's records, treatment notes, and other essentially textual data. These are unlikely to pose a significant burden on even the most primitive communication systems.

One dimensional data: Files are data sequences, such as audio, or instrument telemetry. It may be desirable to store these files, and forward them when they are complete, but it is more likely they will be transmitted in real time. Uncompressed CD quality audio consists of 16 bit measurements taken approximately 44,100 times a second. This requires a bandwidth of approximately 88.2 Kbytes/sec. Instrument telemetry should fall in a similar range, or may be distributed as a graphic file.

Two dimensional data: Data Consists of still images. Computer image are stored as grids, in which the squares (called pixels) each can be a different color. The size of the image can be determined by multiplying its width in pixels times its height in pixels, times the number of different colors a pixel can possess. 24 bit color is generally assumed to be photorealistic, or sufficiently subtle to display the smallest differences the human eye can perceive. 16 and 8 bit color are also common (displaying 32,768 and 256 different colors, respectively.) Some common image sizes are listed below:

Magnetic Resonance Study: 256x256 pixel images, 8 bit color, 20-40 frames per study ~ 2MB per study.

CT study: 512x512 pixel images, 8 bit color, 20-40 frames per study ~8 MB per study.

Radiogram: 2048x2048, 12 grayscale ~ 6 MB

Three dimensional data: Three dimensional data is an image which changes in time, a movie. Again, these must be sampled at a certain time rate. 60 fps, or frames per second is generally considered to provide for full-motion video (indistinguishable from life). High quality video, depending on the exact parameters involved, requires anything from tens to over a hundred Mbytes of storage per second of video. If this video is to be transmitted in real time, then the communications link must be capable of transmitting many megabytes of data per second.

5.1 Hardware Links

Cables: Cables are the connection along which the signal actual travels. There are many different sorts of cable currently in use.

Coaxial Cable: This is a cable with a solid central conductor, surrounded by an insulating shell, which is in turn shielded by a wire mesh. It is often used to carry high frequency signals such as video or radio.

Twisted Pair: This is cable where two conductors are twisted together. This cable may be either shielded or unshielded.

Optical Fiber: Optical Fiber is made from plastic or glass, and information is transmitted along it in the form of pules of a laser. It is cheaper, and less susceptible to external noise than copper wire, but more difficult to connect.

Routers: A router is a device which forwards information within or between networks.

Concentrator: A concentrator is a device which takes many inputs, and combines them into a single, higher bandwidth output.

Modems: A modem is a device which can transmit and receive digital information over a conventional analog phone line. It accomplishes this by encoding the data as a series of tones, which are decoded at the other end. The speed of modems is generally expressed in baud, or bits per second. Early modems were able to transmit data at between 300 and 1200 baud. Newer

modems transmit at 2400, 9600, 14400 and 28800 baud. A connection between two modems is limited to the speed of the slower modem, and may be further limited by the amount of noise on the telephone line.

5.2 Network Types

Local Area Network (LAN): The Local in LAN generally refers to an area ranging from the interior of an office, to one encompassing a city block. LANs are generally built using connections explicitly laid for that purpose, and provide a high speed, low cost way to share information.

Common commercial LANs are Ethernet and Token Ring, which provide transfer rates of 10Mbps and 16 Mbps respectively. Higher throughput can be achieved by using multiple wires, or fiber optic cable. There are currently several competing standards for 100 Mbps capable LANs.

Wide Area Network (WAN): Wide Area Networks are of special interest in telemedicine, since they generally cover whole continents, or even span the globe. These networks form the basis of the global telephone system. Unlike Local Area Networks, modifying or adding to the hardware of a WAN is a monumental task, simply because of the scale of the changes which must be made.

WANs can easily be broken down in terms of the bandwidth they deliver. X.25 is an existing low bandwidth network, as is N-ISDN. B-ISDN and systems implemented on top of SONET would represent broad band services.

The Internet: The Internet is a logical network which spans many physical networks. It grew up around the backbone networks of ARPAnet and NSFnet, networks laid to facilitate scientific collaboration, and MILNET, a military network. Tens of thousands of local networks have attached to the Internet, providing a network which spans the globe, as well as many different communication and networking protocols.

5.3 Network Protocols

TCP/IP: TCP/IP is in fact not one communications protocol, but two. Together, the protocols form the network and transport layer for Ethernet. The TCP/IP protocol is used by many UNIX systems. Because TCP/IP includes the IP protocol, which is best effort, it is poorly suited to transmitting real-time sound and video data, since it cannot guarantee a constant bandwidth between any two points in the network.

TCP: Transmission Control Protocol forms the transport layer of the TCP/IP standard. It ensures a full duplex, multi-plexing, connection oriented link. In addition, the link is reliable. In this context that means that the packets sent along the link are complete, uncorrupted, and in the same order as they were sent. TCP is found in most UNIX systems. Those systems that do not use TCP generally use UDP.

IP: Internet Protocol is the network level standard on which both TCP and UDP are built. IP is connectionless, and based on a best effort method of routing. This means that a fixed bandwidth between any two points on the network cannot be guaranteed, but will instead be dependent on the load on the network at any given time.

UDP: User Datagram Protocol is a common alternative to TCP. It is a connectionless protocol which includes a check-sum, but does not correct for packets which arrive out of order, nor does it guarantee delivery. As a result it is a very simple protocol, since all error-processing and retransmission must be taken care of by the application program. UDP provides network

layer, transport layer and session layer protocols. A datagram is simply a packet in a connectionless protocol.

- Thick Coaxial Ethernet, 10Base5
- Thin Coaxial Ethernet, 10Base2
- Twisted-Pair Ethernet, 10Base-T
- Fiber Optic Ethernet, 10Base-F

In addition, a standard for 100 Mbps exists. This bandwidth may be achieved using fiber optic cable, and two or four pair twisted pair cable.

ATM: ATM or Asynchronous Transfer Mode is a standard designed to provide multimedia service over a network ranging in size from a LAN to a WAN. ATM does not fit well into the OSI network hierarchy, as it provides services from both the Data Link and the Network Level.

ATM is an attempt to improve on STM, or synchronous transfer mode. In a connection based synchronous link, a certain bandwidth is guaranteed between two points. Under normal conditions, much of this bandwidth may go unused, although the full bandwidth is necessary to ensure real-time delivery of a "bursty" signal. ATM attempts to utilize these gaps to provide more efficient user of the total resources of the network, while still ensuring that users will have access to the desired bandwidth on demand.

ATM does this by splitting all communications into 53 byte long packets. By ensuring small, fixed size packets, and rapid error recovery and routing, ATM attempts to gain the efficiency of packet switching while still providing the "bandwidth on demand" of a connection based link.