Mobile Telemedicine Testbed

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INTRODUCTION

The project Team of BDM, the University of Maryland at Baltimore (UMAB), and HCI Technologies has been investigating the feasibility and practicality of transmitting real-time patient vital signs data, audio, and video images of care activities from inside an ambulance en-route to a trauma center using wireless digital cellular communications and in-hospital Intranet technology. The objective of the mobile telemedicine testbed is to determine if the system can improve the quality and timeliness of care provided during the "golden window" of treatment opportunity immediately following injury, and provide better information to the hospital staff prior to patient arrival.

Our Team has been building upon proof-of-concept projects performed by Emory University School of Medicine[1] and University of Texas Herman Hospital[2]. Both of these projects demonstrated the feasibility of key components of our project and determined that there was clinical value to the approach. Both concluded with recommendations that additional work be performed.

SYSTEM DESCRIPTION

Key to the success of the mobile telemedicine testbed is the tight integration of existing commercial technologies and the use of open-system standards. This approach uses proven, modular components to keep costs low, mitigate system risk, and to simplify the introduction of new technological developments.

Remote (Ambulance) Equipment

Our system architecture (see Figure 1) integrates the following commercial components within the remote ambulance:

- Digital camera, TV, microphone, and VCR,
- Patient vital signs monitoring equipment,
- Patient record entry system, a docking tablet computer with touch-screen and handwriting recognition software,
- Video and Communications system, that integrates camera inputs while managing a parallel array of 2-8 digital cellular phones.

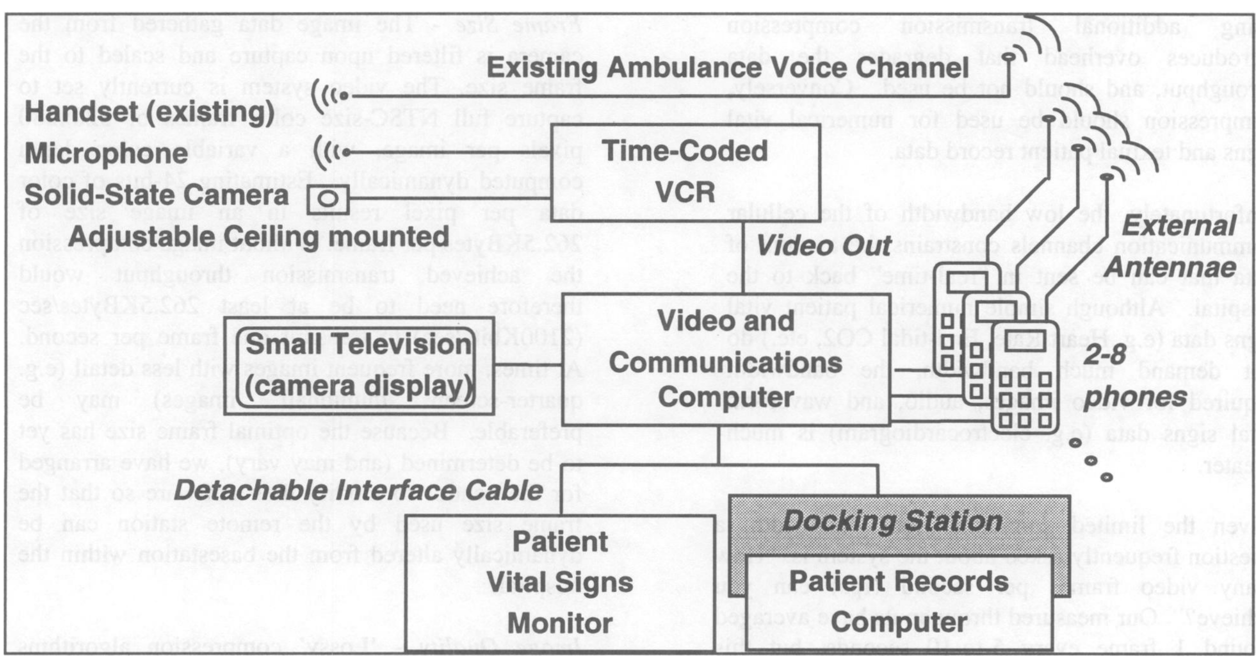

Figure 1: Ambulance Equipment Configuration

Patient vital signs data are captured from the monitoring equipment by the patient records computer. The patient data are transmitted (along with any patient records entered by the paramedics) to the video processing computer. The video system integrates the patient data with the input video data for communication back to the hospital. The VCR is used to record ambulance audio and video data, allowing us to perform post-transit data comparisons against the transmitted information. The data transmission uses multiple cellular phones in parallel (i.e. simultaneous transmission over multiple phones) to increase the system throughput.

Although data bandwidths for digital cellular communications are relatively low when compared to alternative transmission schemes (e.g. 9.6Kbits/sec vs 56Kbits/sec for satellite communications[3]), throughputs are expected to increase significantly over the next two years. Furthermore, the use of digital cellular communications provides advantages that include an encrypted signal for data privacy, transmission delays that compare favorably with land-line modems, and a relatively inexpensive pricing model that is expected to improve further due to heated market competition.

It should be noted, however, that vendor specifications for channel bandwidth presume "best-case" compressible data that is text only. Because video/image data is already compressed, using additional transmission compression introduces overhead that degrades the data throughput, and should not be used. Conversely, compression should be used for numerical vital signs and textual patient record data.

Unfortunately, the low bandwidth of the cellular communication channels constrains the amount of data that can be sent in "real-time" back to the hospital. Although simple numerical patient vital signs data (e.g. Heart Rate, End-tidal CO2, etc.) do not demand much bandwidth, the bandwidth required for video images, audio, and waveform vital signs data (e.g. electrocardiogram) is much greater.

Given the limited communications bandwidth, a question frequently asked about the system is: "How many video frames per second (fps) can you achieve?" Our measured throughputs have averaged around 1 frame every 5-to-10 seconds, but this answer is misleading. Our testing has shown that a number of variables interact to impact the frequency and quality of the remote video transmission.

Available Bandwidth - The amount of wireless bandwidth available directly impacts the speed with which frames are transmitted. Although each cellular phone channel has a theoretical speed of 9.6Kbits/sec, our connectivity testing measured realized throughputs of around 5Kbits/sec. These speeds may be slightly improved by optimization of the communication settings (e.g. by disabling the redundant Radio Link Protocol) to reduce the signaling overhead. Two phones operating in parallel would result in approximately 10Kbits/sec throughput. Adding additional phones increases the available bandwidth, but the limits of the scalability are currently unknown.

Camera Resolution - The amount of image data captured by the digital camera impacts the quality of the image and the amount of the data to be transmitted. This testing also showed that performing image stabilization will not be necessary unless the frame rates can be raised to near 30 frames/second. Therefore, we have modified our initial hardware architecture to allow for the quick disconnection and replacement of the camera; this will allow different cameras to be tested. The cameras used for operational testing will capture 24-bit color images at 640x480 pixels, a resolution superior to NTSC television.

Frame Size - The image data gathered from the camera is filtered upon capture and scaled to the frame size. The video system is currently set to capture full NTSC-size color frames of 320x280 pixels per image, with a variable color depth computed dynamically. Estimating 24-bits of color data per pixel results in an image size of 262.5KBytes per frame. Without image compression the achieved transmission throughput would therefore need to be at least 262.5KBytes/sec (2100Kbits/sec) to transmit one frame per second. At times, more frequent images with less detail (e.g. quarter-screen "thumbnail" images) may be preferable. Because the optimal frame size has yet to be determined (and may vary), we have arranged for the vendor to modify their software so that the frame size used by the remote station can be dynamically altered from the basestation within the hospital.

Image Quality - 'Lossy' compression algorithms degrade the image quality in relation to the amount of data compression. A greatly compressed image will transmit faster, but will result in an image of lower quality than the original. Our system is currently optimized for using JPEG compression. Although the vendor is actively exploring alternative image compression algorithms (e.g. fractal, wavelet, etc.), different compression algorithms each have different advantages and disadvantages[4]. Because the best combination of speed and image quality has yet to be determined, we have arranged for the vendor to modify their software to allow the compression ratio of the remote stations to be dynamically altered from the basestation within the hospital. Depending upon achieved throughputs and project resources, we may change to a combined fractal/wavelet commercial algorithm for our image compression.

Each of these variables are tunable within our the system architecture, requiring operational testing to determine the best combination. A better question to ask would be: "How many frames, and of what type of frames, are needed to be clinically useful?" We anticipate that the answer will depend upon the clinical model to which the system is applied; we have therefore designed the system to allow for the dynamic adjustment of the system parameters in order to optimize system performance. Except for image content, each variable is also subject to continuous improvement via new technology development.

Hospital Intranet Configuration

Upon the hospital side, data is received over regular land-line modems and stored on a secure Microsoft NT server. Data on the server is held within the Microsoft SQL relational database, with image data held by reference to the corresponding image files. The database is interfaced with the Microsoft Internet Information Server (a web server) to make the data available over the hospital Intranet. Physicians use a simple web-browser client (e.g. Netscape or Internet Explorer) to access an ambulance's data in real-time over the hospital LAN from their desktops.

Our software architecture leverages the latest "Server-Push" technology to update the desktop display. A secure HTTP connection is established from the desktop client to the Intranet server that is kept open by the client. As new data arrives from the ambulance into the server, our JAVA software on the server generates dynamic HTML updates that are automatically transferred to the client. This approach continually presents the viewer with the latest data received, without requiring the user to initiate frequent requests for data updates.

This approach has several advantages over a more traditional client/server approach. All custom software is 'hidden' from the users, running upon the backend web/database server. No custom client software is needed, keeping client costs at a minimum. Further, database licenses are only needed for the web server connection to the database, minimizing the costs associated with adding additional users. All components within the architecture remain based upon open Internet standards, allowing the rapid adoption of technology improvements.

EVALUATION METHODOLOGY

Careful evaluation of the effectiveness of a telemedicine system must look beyond the technology used and examine not just the effects of the system on quality of care, but must also consider the system costs[5]. Our evaluation methodology includes cost-benefit analysis of the system effectiveness. Although we anticipate significant benefits through speedier diagnosis and treatment, these must be weighed against the system costs to justify the expense.

We have chosen to use the inter-hospital transport of brain attack (acute stroke) patients for our evaluation model. This model allows a neurologist to remotely assess neurological status of a stroke patient, with the help of the on-board paramedics. This assessment is made using a combination of transmitted audio, still images, video segments, vital signs, and blood chemistry data. Once proven, our intent is to extend the use of the system to other patient transport and emergency pre-hospital care models, such as emergency accident (i.e. 911) calls.

Our model was chosen with the collaboration of Maryland ExpressCare and the Maryland Brain Attack Center (MBAC). Maryland ExpressCare is the primary critical patient transport company for the University of Maryland Hospital, and has generously supported the project with the goal of improving operations through early adoption of the developed technology. Maryland ExpressCare primarily transports patients between hospitals. Although most of the transported patients are in critical condition, transport is usually arranged in advance. Because of such relative control when compared with transports from accident scenes, ExpressCare provides a good vehicle for investigating mobile telemedicine with unproven technologies (as planned here).

The MBAC is a specialist team formed in August 1996 to speed the treatment of brain attack patients. Treatment options used for acute stroke victims are constrained by the delay between symptom onset and definitive diagnosis. The FDA-approved treatment protocol requires that recombinant human tissue plasminogen activator (t-PA) must be administered within three (3) hours of symptom onset[6]. Delays in receiving treatment result in only around 3% of the patients that could potentially benefit from receiving t-PA. Other time-sensitive treatment protocols are also under clinical trial within the MBAC. By using the mobile telemedicine system to transmit diagnostic information en-route, we believe we will be able to significantly shorten the delays to therapeutic treatment, increasing the available treatment options and improving patient outcomes.

The concern has been raised that inter-hospital transfer of brain-attack patients presents a flawed evaluation model because of the inability to control for patient interventions prior to patient pick-up. This uncontrolled variable would likely impact patient outcomes, compromising the data assessment.

Recognizing that clinical outcomes would be an inappropriate metric for this study, the metric '*time to definitive diagnosis*' will be used to measure the clinical effectiveness of the system. The clinical effectiveness of the enhanced telecommunications will be measured by the saved time to definitive diagnosis of stroke by the neurologist following admission to the University of Maryland Hospital. Benefits of the time saved can be calculated by the potential savings in hospital resources and long-term patient care. Patients with stroke transported prior to the study will be used as controls and compared to those transported during the study. Broader future studies that include clinical outcomes and wider patient populations have been planned.

NEXT STEPS

The implementation of the Mobile Telemedicine Testbed was underway at the time of submission. We plan to begin operational testing of the system during the July 1997 timeframe. Once proven within the given evaluation model, our team plans to extend the use of the system to additional patient populations and to alternative pre-hospital care situations.

CONCLUSIONS

The technologies required to transmit live patient vital signs, image, and audio data from an en-route ambulance to the hospital are being evaluated within the context of speeding the diagnosis of Brain Attack patients. The Mobile Telemedicine Testbed uses modular, commercial components, allowing alternative subsystems or algorithms to be quickly tested. Initial testing shows promise that this system will prove both clinically significant and cost effective.

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