Case Study

Impact of Varying Transmission Bandwidth on Image Quality

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ABSTRACT

The objective of this paper is to determine the effect of varying transmission bandwidth on image quality in laparoscopic surgery. Surgeons located in remote operating rooms connected through a telemedicine link must be able to transmit medical images for interaction. Image clarity and color fidelity are of critical importance in telementoring laparoscopic procedures. The clarity of laparoscopic images was measured by assessing visual acuity using a video image of a Snellen eye chart obtained with standard diameter laparoscopes (2, 5, and 10 mm). The clarity of the local image was then compared to that of remote images transmitted using various bandwidths and connection protocols [33.6 Kbps POTS (IP), 128 Kbps ISDN, 384 Kbps ISDN, 10 Mbps LAN (IP)]. The laparoscopes were subsequently used to view standard color placards. These color images were sent via similar transmission bandwidths and connection protocols. The local and remote images of the color placards were compared to determine the effect of the transmission protocols on color fidelity. Use of laparoscopes of different diameter does not significantly affect image clarity or color fidelity as long as the laparoscopes are positioned at their optimal working distance. Decreasing transmission bandwidth does not significantly affect image clarity or color fidelity when sufficient time is allowed for the algorithms to redraw the remote image. Remote telementoring of laparoscopic procedures is feasible. However, low bandwidth connections require slow and/or temporarily stopped camera movements for the quality of the remote video image to approximate that of the local video image.

INTRODUCTION

The health of people in developing countries of the world is often compromised by limited access to medical care. Long-distance travel is especially troublesome for very sick patients who are in need of urgent care, including surgery. Any delay in operating on these patients increases their suffering and decreases their chance for recovery. To date, the operating room has been an isolated environment that is inaccessible for real-time consultations based on the exchange of digital images.

While telemedicine can enhance access to and quality of healthcare, some of technology used in telemedicine programs has been expensive, bulky, and not always reliable. The ca-
pability of the Internet to support telemedicine at various bandwidths has been demonstrated by various organizations, including NASA.\textsuperscript{1,2} In contrast to broadband systems, low bandwidth Internet uses readily available, portable, inexpensive equipment. However, it is unclear if the limited bandwidth can support medical applications that require high-quality video images as in surgery. Live surgical procedures have been evaluated over Internet\textsuperscript{2}.\textsuperscript{3} However, Internet\textsuperscript{2} is not available in many parts of the world where telemedicine can improve access to quality care.

To date, surgical applications of low bandwidth telemedicine are not well developed. Laparoscopy is minimally invasive surgery that uses video cameras and instruments inserted through small incisions to perform such operations as cholecystectomy and appendectomy.\textsuperscript{4} It tends to decrease postoperative recovery time, pain, and scarring. Of course, small incisions necessitate the use of a small diameter endoscope.\textsuperscript{5} However, the effect of decreasing laparoscopic diameter on image quality has not been evaluated.

This study investigated the effect of varying laparoscope diameter and transmission bandwidth on image quality to determine the feasibility of low bandwidth remote supervision of endoscopic abdominal (laparoscopic) surgery.\textsuperscript{6}

**MATERIALS AND METHODS**

A surgical team from Virginia Commonwealth University’s (VCUs) Medical College of Virginia (MCV) was connected via regular telephone lines to surgical suites in Ecuador and Dominican Republic. A portable satellite phone (Inmarsat M-4) was used with a connection rate of 64 Kbps. The purpose of the project was to evaluate the effect of varying transmission bandwidth on image quality in laparoscopic surgery.

A standard Snellen Eye Chart (Rosenbaum Pocket Vision Screener) was held 14" from the lens of various acquisition devices, which are 2-, 5-, and 10-mm laparoscopes (Stryker Corp., Santa Clara, CA) with a 3-CCD (Charged Coupled Device) camera. The Snellen chart was locally displayed on a standard video monitor and a researcher with 20/20 vision identified the letters on the chart. The chart was sent from different locations within the university using various bandwidth connections to the laboratory, and the researcher identified the letters on the chart. The specific bandwidths were: 33.6 Kbps Internet Protocol (IP), 128 Kbps Integrated Services Digital Network (ISDN), 384 Kbps (ISDN), and 10 Mbps Local Area Network (LAN). The connections used H320 for ISDN and H323 for IP. The tests were repeated with

<table>
<thead>
<tr>
<th>TABLE 1. EQUIPMENT AND SPECIFICATIONS USED TO COLLECT AND VIEW DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Viewing station</strong></td>
</tr>
<tr>
<td>Compaq Presario Windows 95; Pentium II, 400-MHz, 96-MB RAM</td>
</tr>
<tr>
<td>Compaq MV520 14&quot; monitor (CRT)</td>
</tr>
<tr>
<td>Hardware acceleration: maximum</td>
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<tr>
<td>True color (32-bit)</td>
</tr>
<tr>
<td>800 × 600 resolution</td>
</tr>
<tr>
<td>8-MB video RAM</td>
</tr>
<tr>
<td>S3 Inc. Savage 4 GT controller</td>
</tr>
<tr>
<td>Gamma settings: 2.2</td>
</tr>
<tr>
<td>Refresh rate 85-Hz vertical</td>
</tr>
<tr>
<td><strong>Video sources</strong></td>
</tr>
<tr>
<td>Nogatech video interface card, s-video interface</td>
</tr>
<tr>
<td>Intel TeamStation, s-video interface to PictureTel EVI-D30 camera</td>
</tr>
<tr>
<td>2-, 5-, and 10-mm Stryker laparoscopic scopes</td>
</tr>
<tr>
<td>Intel YC66 digital video camera via PCI card</td>
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<tr>
<td><strong>Room lighting</strong></td>
</tr>
<tr>
<td>Philips Bulb</td>
</tr>
<tr>
<td>F32T8/TL735/ALTO</td>
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<tr>
<td>Watts</td>
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\textsuperscript{1,2}"
each image acquisition device positioned in front of the Snellen chart at an optimal distance for displaying the image.

The image acquisition devices were then used to view a standard color placard, which were sent by similar transmission bandwidths and connection protocols. The local and remote images of the color placards were compared to access the effect of the transmission protocol on color fidelity. Two placards were made, each comprised of nine 1 × -2" swatches. One placard was used to measure grayscale values ranging from 25% black to 100% black. The second placard used combinations of red, green and blue (RGB) (100% of one color, 100% of two colors, and 100% of all three colors).

RGB values provided the most practical and effective measurement for video images because they form the basis of visible light for all computer and video systems. An RGB triad represents a single picture element (pixel). Therefore, a single value from that triad cannot be meaningful in measuring deviation without the context of the other two values. RGB values typically are represented from 0 to 255, and combined range from 0, 0, 0 (Black) to 255, 255, 255 (White). Collectively, these values represent all aspects of color, including hue, saturation, and value, and the absolute and relative motion of these values within a triad can represent a shift of some or all of these aspects. Only by looking at the context of a numerical shift can one determine if the change affects hue, saturation, and/or value.

To compare color values, each swatch was scanned using a Microtek (Microtek Lab, Inc., Redondo Beach, CA) Scanmaker 4 scanner. The RGB values were measured from each swatch using Adobe (Adobe Systems, Inc., San Jose, CA) Photoshop’s eyedropper tool. Before measuring, individual color swatches were averaged within Photoshop using a custom script to eliminate pixel variations in specific areas. In addition, three equidistant areas within each swatch were measured, and the numbers were averaged for a final representative value. Local and remote images of each swatch were “screengrabbed” as a 24-bit image. RGB values were calculated using the procedure described above. Color fidelity was determined by comparing the individual RGB values of the local and remote images.

The testing procedure for color fidelity was designed to measure deviation introduced by the transmission protocols. Hence, it does not take into account other external factors that affect video image quality on a daily basis. As an example, the normal electronic and mechanical variance of manufacturing for video display units, variations in ambient and local lighting, as well as the different technologies used for displaying video images (LCD, CRT, projection, reflection, multiscan and single-scan, etc.) will have a significant impact on the perceived quality of a video image from the standpoint of an observer, even with the same source data. Because measurements are done in the computer (prior to display) and not by an observer, the display and perceptual error are not measured. But, they should be considered in actual use of video equipment.

All test measurements and human interpretations were made on the same computer and monitor with controlled lighting conditions (See Table 1). Video sources varied to accommodate the various acquisition methods and were analyzed accordingly (See Visual Acuity—Snellen diagram in Fig. 1).

RESULTS

Image clarity

When held 14" in front of the Snellen chart, the clarity of the local image improves with use of larger diameter of laparoscopes. However, there is no significant difference in clarity of the local image between various diameter laparoscopes when the laparoscopes are positioned in front of the chart at the distance that results in the highest optical quality. While the focal ranges of the laparoscopes are similar (approximately 5 mm to infinity), the difference in the clarity of the local images when the laparoscopes are positioned at 14" from the Snellen chart is primarily related to a difference in illumination. Smaller diameter scopes simply do not provide adequate light to view the chart from the 14" distance. The field of vision of the
smaller diameter laparoscopes is smaller than the field of vision provided by the larger laparoscopes. Figure 1 illustrates the visual acuity of the Snellen chart.

The clarity of the local and remote images is nearly equal, regardless of bandwidth. The compression algorithms tend to preserve image clarity over the range of bandwidths provided the frame is redrawn through a full cycle of image changes (deltas), which is 15 seconds. By default, NetMeeting uses the low-bandwidth coders/decoders (CODEC)s G.723.1 for audio and H.263 for video. For example, the G.723.1 audio CODEC requires only 6.4 Kbps, plus approximately 40% for the IP packet header and overhead. Higher bandwidth CODECs are used only if the network link has sufficient bandwidth to support less compression. The user can select these manually through use of a drop-down menu. Unlike other programs such as White Pine’s CUSeeMe, it is not possible to measure the frame rate in Microsoft NetMeeting. According to Microsoft, the frame rates ranges from 7 to 30 fps depending on processor speed, application version, window size, quality setting and bandwidth available (http://support.microsoft.com/support/kb/articles/Q186/8/67.ASP). Although the frame rate can be as high as 30 fps under ideal conditions, deltas are used to facilitate image changes at 15-second intervals. Though the visual data within the frame are updated on a varying but regular basis, no single frame is sent as a complete unit more frequently than every 15 seconds. Variation in update speed for different portions of an image produces the progressive focus effects described here, where the video needs to be still to “fill in” detail over successive frames. This is different from any other video technology where the relative motion of the camera has no affect on image quality so long as the speed of motion is within the tolerance of the camera’s own shutter speed and does not blur the image.

Color fidelity

When held 14” in front of the Snellen chart, color fidelity of the local image improves with larger diameter laparoscopes. The darkening of colors in the local image seen with small diameter scopes is probably the result of de-
creased illumination provided by the smaller scopes, whereas lightening seen in larger scopes results from possible overexposure. Laparoscope cameras have automatic shutters that tend to compensate for overexposure and underexposure, but they do not eliminate "blooming." Hence, there seems to be a correlation between low bandwidth transmission and darkening of image (Fig. 2).

Comparison of the local and remote images demonstrated no significant changes in color because of video compression and transmission, and the color green was the most accurately preserved color. Because green carries the most visual information, CODECs were presumably developed to preserve it. Lighter hues of red and blue were accurately reproduced, and darker hues of these colors were either lightened or blackened by the CODEC. In general, the degree of change of reds and blues in the remote image were independent of bandwidth (Fig. 3).

**DISCUSSION**

This study demonstrated that remote image quality was preserved over a wide range of transmission bandwidths. Subsequently, surgeons from VCU-MCV validated these experiments by tele-proctoring laparoscopic cholecystectomies over low bandwidth connections. While the medical applications of Internet-based videoconferencing are significant, successful use of low bandwidth videoconferencing requires rudimentary understanding of current video compression and transmission software. Videoconferencing software over IP (such as Microsoft NetMeeting or White Pine CUSeeMe) uses a different method of data transfer than a "traditional" Transmission Control Protocol (TCP)/IP application such as a web browser. In the familiar TCP/IP, several communications are made from system to system to verify that the data has been received properly, thereby, al-

**FIG. 2.** Average deviation of color values in comparison of color in remote and local images. The range of possible values is 255 with negative numbers indicating darkening and positive numbers indicating lightening. This is the average of the entire color triad, not of individual RGB component values, and as such primarily represents overall changes in value.
lowing for error-correction and insuring data integrity.

The likelihood of any given packet of data being lost or misdirected does not vary by protocol because it is subject to the same variable circumstances of line noise, timeouts, excessive routing, and malicious packet removal. In general, it is safe to assume that the greater the number of systems between points on a Transport Protocol voer User Datagram Protocol (RTP/UDP) connection, as well as the greater geographic distance, the more likely that packets will be lost with greater frequency. In addition, the quality of network and phone services on any branch of the connecting network will greatly affect the frequency of data loss. Hence, poor telecommunications systems may be incapable of establishing a reasonable RTP/UDP connection, while good networks may not have packet loss.

Data loss results in degraded image and poor audio quality. Image quality is nearly identical in circumstances where the sending and receiving locations are in close proximity and connected by broadband. However, when distant locations are connected by lower band, the lack of error correction will be noticed as subtle changes in image quality.

During a videoconference NetMeeting sends a complete video frame every 15 seconds, and it sends only deltas between these complete video frames. Broader band connections process and interpret the deltas better, which results in smoother, higher quality video. The use of low-bandwidth connections, make it necessary for operators to minimize camera motion. Low bandwidth, Internet-based telemedicine has been shown to be effective in supporting surgical services in many parts of the world where telecommunications are limited.

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