

Wireless Live Streaming Video of Laparoscopic Surgery: A Bandwidth Analysis for Handheld Computers.

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Abstract: Over the last six years, streaming media has emerged as a powerful tool for delivering multimedia content over networks. Concurrently, wireless technology has evolved, freeing users from desktop boundaries and wired infrastructures. At the University of Kentucky Medical Center, we have integrated these technologies to develop a system that can wirelessly transmit live surgery from the operating room to a handheld computer. This study establishes the feasibility of using our system to view surgeries and describes the effect of bandwidth on image quality.

A live laparoscopic ventral hernia repair was transmitted to a single handheld computer using five encoding speeds at a constant frame rate, and the quality of the resulting streaming images was evaluated. No video images were rendered when video data were encoded at 28.8 kilobytes per second (Kbps), the slowest encoding bitrate studied. The highest quality images were rendered at encoding speeds greater than or equal to 150 Kbps. Of note, a 15 second transmission delay was experienced using all four encoding schemes that rendered video images.

We believe that the wireless transmission of streaming video to handheld computers has tremendous potential to enhance surgical education. For medical students and residents, the ability to view live surgeries, lectures, courses and seminars on handheld computers means a larger number of learning opportunities. In addition, we envision that wireless enabled devices may be used to telemonitor surgical procedures. However, bandwidth availability and streaming delay are major issues that must be addressed before wireless telementoring becomes a reality.

1- Introduction:

Handheld computer technology has been widely recognized for its potential to revolutionize healthcare. Sending medical data to portable devices using wireless protocols has been tested in a variety of medical contexts including patient triage¹, electronic medical record management², telecardiology³ and data acquisition in critical care⁴. However, to date, wireless multimedia applications have not been fully explored for medical education.

At the University of Kentucky Medical Center (UKMC), we used streaming video technology and wireless protocols to create a broadcasting system that enables the transmission of live surgical procedures to handheld computers. This study was conducted to determine the smallest bandwidth required to render quality video images on the handheld display such that the transmitted surgery may be used for teaching purposes. Using five encoding bitrates, a live laparoscopic ventral hernia repair was transmitted to a single handheld computer, and the quality of the resulting streaming images was evaluated.

2- Materials And Methods:

After obtaining formal patient consent, a laparoscopic ventral hernia repair was transmitted live from a UKMC operating room to the handheld device using the following model, which integrated wired and wireless computer systems equipped with off-the-shelf software/hardware.

2.1 Model for live streaming video transmission (see Figure 1)

2.1.1 Wired Components and Configuration

The key hardware components of the wired system included a video monitor located in the operating room, a video HUB (provided by Stryker), a desktop computer (Optiplex by Dell) that functioned as a server, and a capture card (Belkin). Important desktop computer software included Windows Media Encoder™. The operating room video monitor, the video signal source, was connected to the server (the desktop computer) via the in-house videoconference router. The server was equipped with a Pentium III 750 MHz processor, 128 MB of RAM, a Windows 2000 operating system, the capture card, and Windows Media Encoder™. The server's encoding bitrate was modified to the following five schemes: 28.8 Kbps, 56 Kbps, 150 Kbps, 250 Kbps and 300 Kbps. The desktop was connected to the private LAN, and the encoder was configured to stream video images at 15 frames per second (fps), the maximum streaming rate that the handheld computer's central processing unit (CPU) can process.

2.1.2 Wireless Components and Configuration

The key hardware components of the wireless system included a handheld computer (iPAQ 3670 by Compaq), a wireless PC card (RangeLAN 7410 CE by Proxim, Inc.), a wireless Ethernet Access point (RangeLAN2 by Proxim, Inc.), and a HUB/router device (Netgear) to establish a private LAN. Important handheld computer software included Windows Media Player™ version 7.1 for Windows CE.

The iPAQ 3670 was equipped with 64 MB of RAM, a 206 MHz Intel StrongARM 32-bit RISC Processor, a Pocket PC 2001 operating system operating on a Windows CE 3.01 platform and the Windows Media Player™ software. The iPAQ display technology included a 240 X 320 pixel touch screen and a color reflective thin film transistor (TFT) liquid color display (LCD) with 4,096 colors. The wireless PC card was connected to the iPAQ using an expansion pack compatible with type II PC cards. The wireless PC card was connected to the wireless Ethernet Access Point, which connected the iPAQ to the private LAN HUB/router. The wireless PC card and the Ethernet Access Point transmitted on a 2.4 GHz radio spectrum, the OpenAir standard, using the 802.11 b wireless protocol.

2.1 The working model (see Figure 1)

Analog video signals originating from the operating room monitor were transmitted to the server via the Stryker video HUB. The capture card received the analog signals and converted them into a digital format. Windows Media Encoder™ then encoded the digital video signals to streaming video format. In order to receive the streaming video images from the server, the researcher turned on the handheld device (the iPAQ connected automatically to the private LAN via the PC card/Access Point link described above) and launched Windows Media Player™. The researcher then entered the server's Intranet Address, and the real-time streaming video images were received and rendered on the handheld device.

Figure 1: Wireless Transmission of Live Streaming Video to a Handheld Computer



3- Results:

After entering the server's intranet address, 30 seconds were required for the iPAQ to connect to the server. Once connected, we attempted to transmit the surgery at five different encoding bitrates (28.8, 56.2, 150, 250 and 300 kbps) while the server's configured frame rate was held constant (15 fps). While transmitting at each encoding bitrate, overall video quality was subjectively assessed in terms of the image rendered and the continuity of motion. In addition, one objective parameter related to video quality was recorded, the resulting frame rate (see Table 1). Other parameters recorded during transmission included bandwidth availability and the transmission range.

In summary, sound and video images were successfully transmitted to the iPAQ using 4 out of the 5 encoding rates studied (56.2, 150, 250 and 300 kbps). At 28.8 kbps, only sound was transmitted. The highest quality video was achieved at bitrates greater than or equal 150 kbps. Significantly, video quality was not improved by increasing the bitrate from 150 to 250 to 300 kbps even though the resulting frame rate did increase slightly (13.1 to 14.0 to 14.3 fps). In addition, a 15 second video transmission delay was observed with all 4 encoding rates (56.2, 150, 250 and 300 kbps). The model accommodated a maximal radial transmission range of 500 feet around the Ethernet Access Point. The "bandwidth available" to carry the video data was always less than the configured encoding bitrate due to network traffic, which affected the frame rate.

Table 1: Video Quality, Bandwidth Availability and Frame Rate at Different Encoding Bitrates*

Encoding Bitrate (kbps)	Bandwidth Availability (kbps)	Frame rate (fps)	Video Quality
28.8	23.8	0	No video image rendered
56.2	36.7	11.3	Blurry Image, choppy motion
150	146.3	13.1	Crisp image, smooth motion
250	225	14.0	Crisp image, smooth motion
300	280	14.3	Crisp image, smooth motion

*Configured frame rate held constant at 15 fps

4- Discussion:

Encoding bitrate and frame rate are two major determinants of what we perceive as video quality. Essentially, video is a sequence of still images known as frames that, when displayed in succession at high rates, are perceived as being in fluid motion. Encoding bitrate represents the amount of data transmitted in one second to create the still image. The higher the encoding rate, the clearer and more detailed the still image. As the frame rate (the rate at which still images are displayed) is increased, the motion of that image is perceived as increasingly fluid. High quality video such as that seen on television and in movie theaters is accomplished using frame rates of 30 and 24 fps, respectively. Therefore, to maximize video quality, one would ideally transmit data at the highest possible encoding bitrate and frame rate.

However, factors exist that limit the video quality rendered by our model. Currently, handheld computers are manufactured with central processing units that cannot render images at rates greater than 15 fps, the frame rate used in this study. In addition, the algorithm used by Windows Media Encoder™ to compress video and audio data into a specific bandwidth limits the encoding bitrate that can be used. Before analog video can be transmitted to a hand held computer, it must be digitized and then compressed so that the video data will fit within the bandwidth selected for smooth streaming. More importantly, using more sophisticated compression algorithms to increase the encoding bitrate also uses more hardware resources and increases the cost of transmission because more data must be delivered over the network.

Significantly, our study found that, given its limitations, our model was capable of transmitting a live surgical procedure to a handheld computer and that the video rendered was of sufficient quality to allow the researcher to easily follow the procedure from beginning to end. Therefore, the model may potential be used in surgical education. In addition, the study found that increasing the encoding bitrate from 150 to 300 kbps did not enhance the quality of the video, which was subjectively assessed. This information has economic implications for institutions with limited budgets that may plan use our model. Using an encoding bitrate of 150 kbps at 15 fps produces a video of similar quality to that rendered using a bitrate of 300 kbps at 15 fps without spending as twice as much.

Our model may be enhanced by incorporating software with more powerful compression algorithms. In 1998, the International Organization for Standardization (ISO) and the International Engineering Consortium (IEC) combined forces to create a new standard for the compression of audio and video signals known as Moving Picture Expert Group or MPEG. This group published several standards that allow video compression at rates ranging from 1.5 Mbps (MPEG-1) to 20 Mbps (MPEG-2). The MPEG-4 standard was first published in 1998 and enabled video encoding at rates as low as 5 kbps to a maximum of 5 Mbps. As a result, MPEG-4 compression algorithms provide high quality video that can be delivered over limited bandwidth

to wireless-equipped handheld computers or cellular phones loaded with video streaming software.

In addition to advances in data compression, developments have also been accomplished in data transfer using wireless protocols. In 1990, the Institute of Electrical and Electronics Engineers (IEEE) 802 Executive Group developed standard protocols for a wireless local area network (WLAN) that uses the 2.4 Ghz ISM (Industrial, Scientific and Medical) spectrum. The wireless link between the PC card on the iPAQ and the access point used the 802.11b standard with a total data throughput that ranged from 2.5 to 4Mbps.

During this experiment, although the data transmission was performed in real time, all video images were displayed on the handheld device with a 15 second delay. This is attributed mainly to the buffer effect of the software application that streamed the video images. This setback in data transmission will not limit the use of our model in education, which may include the transmission of lectures or courses, where real time transmission is not crucial. However, improved video interfaces with almost no delay are necessary if real time teleproctoring or even telementoring applications are sought.

In summary, we believe that the wireless transmission of streaming video to handheld computers has tremendous potential to enhance surgical education. Medical training keeps students and residents on the go and scattered throughout the hospital at any given moment, which can make it difficult for individuals to make group sessions and makes it impractical for individuals to rely on static computer terminals to access educational materials. Transmitting live surgery, lectures, courses and seminars to handheld computers overcomes the limitations of relying on static wired hardware to access content^{1,5}. Receiving educational content on handheld computers means that medical students and residents may have more learning opportunities. Although telemonitoring of surgical procedures using wireless enabled devices is technically feasible, bandwidth availability and streaming delay are major issues that must be addressed before such applications are practical. Similarly, live broadcasts of surgical procedures can be performed successfully. However, further studies are needed to establish this technology as a tool that students can learn from.

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