Wireless live streaming video of surgical operations: an evaluation of communication quality

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Summary

We evaluated a mobile video system for surgical teleconsultation. A video streaming server in the operating room transmitted video and audio to a hand-held computer (personal digital assistant [PDA]) over a wireless local area network. Two groups of 20 surgeons (each with 12 qualified surgeons and eight surgeons between the 2nd and the 4th year of training) participated in the tests. For voice transmission, correct understanding of numbers was achieved in 100% of the cases ($n = 1000$) and 98% of medical terms ($n = 400$). The quality of the video displayed on the PDA was assessed by the recognition of different operating room scenarios. Only 62% (SD 17) of the structures were identified clearly on the hand-held device ($n = 400$). The accuracy improved to 78% (SD 15) ($n = 400$) if the same scenario was observed on a larger (50 cm) video screen ($P < 0.001$). Accuracy was significantly better if audio conversation was possible. The quality evaluation by the consultants showed that the PDA display size and quality were sufficient for clinical use.

Introduction

Teleconsultation is already used for intraoperative consultation of external experts who are not physically present in the operating room.[1–3] The main disadvantage is that consultants need appropriate equipment in their offices or must go to a room equipped with telemedicine facilities. To overcome these limitations and to allow spontaneous video communication during routine clinical activities, we have developed a mobile videoconsultation system based on a hand-held computer connected to a wireless local area network (WLAN). This enables audio–video transmission from the operating theatre to be established as required. The first studies have demonstrated that wireless live streaming is helpful in the health-care sector[4,5] and can be useful for educational purposes.[6]

We have evaluated the use of wireless live streaming for clinical and surgical purposes.

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Methods

Operating room equipment

A PC was installed as a streaming server, with a frame grabber board (Videum, Winnov, Santa Clara, California, USA) for capturing the audio and video data. The streamed video data were transmitted through a LAN at 100 Mbit/s. WLAN access points (Netgear MR314, Santa Clara, California, USA) were sited at various places and connected to the network. The access points were based on the IEEE 802.11b wireless standard and provided a connection speed of 11 Mbit/s. For security reasons, the 128-bit Wireless

Encryption Protocol between access points and WLAN controller was used. In addition, MAC Address Authentication over Access Control List was employed. In areas where the wireless signal was weak and installation of an access point to the wired LAN was impossible, wireless repeaters were set up.

For security purposes any connection to the wireless network was recorded in a log with date, time and connection duration together with the IP address, the MAC address of the network card and the name of the client.

The video streaming software (Siemens CTIC2, Munich, Germany) was developed to provide high-quality, live video transmission (in particular with low delay). Commercial streaming applications have the drawback of large buffers to compensate for packet timing jitter in the Internet. These produce long delays, which were not acceptable for our application.

The frame grabbing device provided a video resolution of 176×144 pixels (QCIF format) at 10 frames/s. Compression of the video was achieved by a proprietary MPEG-4 codec (Siemens Corporate Technology, Munich, Germany). In comparison to open source codecs, this special algorithm provided an enhanced prediction functionality to minimize delay and bandwidth. QCIF resolution was chosen in order not to consume the processing power of the PC and to leave some resources for the audio communication. The video could be zoomed to full-screen mode by the client. The simple visual profile of MPEG-4 was used and the Group of Pictures size was set to 100. That meant that, after each intra-coded frame (I frame), 99 predicted frames (P frames) were encoded. This setting ensured good coding efficiency while still allowing from a transmission error in a maximum of 10 s. The video was encoded at variable bit rate, with a resulting bit rate of 450 kbit/s.

Audio connection to the remote consultant was established with the open source Voice over IP software (SJ Labs, Solon, Ohio, USA). The surgeon wore a headset with a microphone, a device which is routinely used for control of peripheral equipment in the operating room.[7]

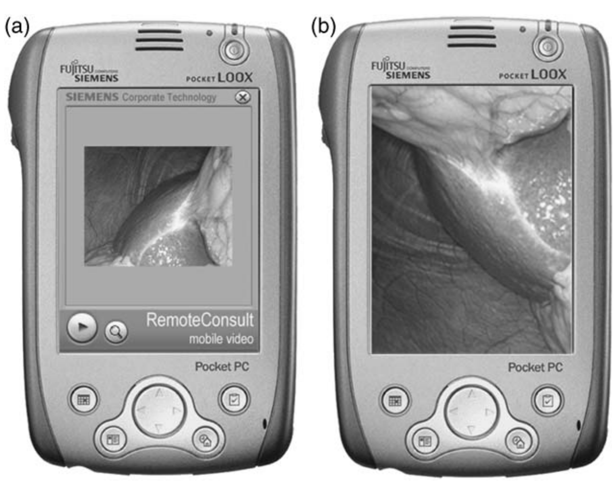

Figure 1 Mobile device with video at original size (a) and zoomed to full screen (b)

Client device

To visualize the streamed video signal, we used a pocket PC (PocketLoox 600, Fujitsu Siemens Computers BV, Netherlands). It was equipped with a 9-cm display with a resolution of 320×240 pixels capable of displaying 65,000 colours (Figure 1). The overall size of the hand-held device was $132 \times 82 \times 17\,mm^3$ and it weighed 166 g. For connection to the wireless network, a WLAN adapter (Socket Communications Inc., Newark, California, USA) was installed in the Compact Flash slot of the pocket PC.

The video client software was based on the proprietary streaming protocol designed to minimize latency as mentioned above and decompress and render the video. It had to be configured with the IP address of the video server from which it requested the video stream. It supported scaling the video to the full display of the device.

For audio connection to the operating room, the pocket PC Version of SJPhone was installed. We configured the software to connect automatically to the identical Windows software on the streaming server in the operating room after start-up (Figure 2).

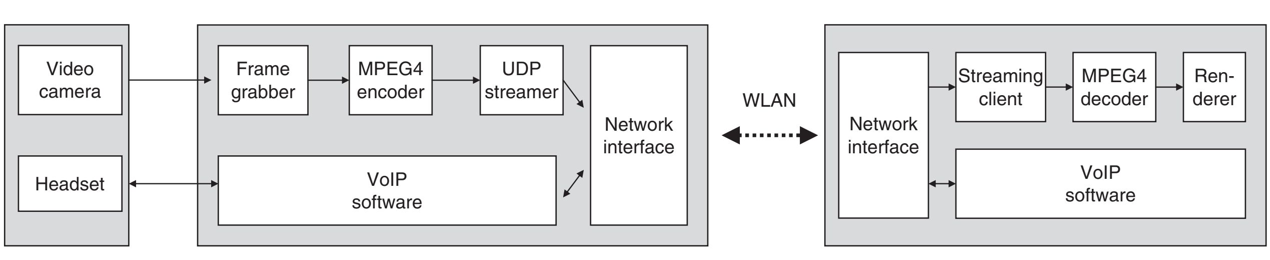

Figure 2 System architecture. OR = operating room

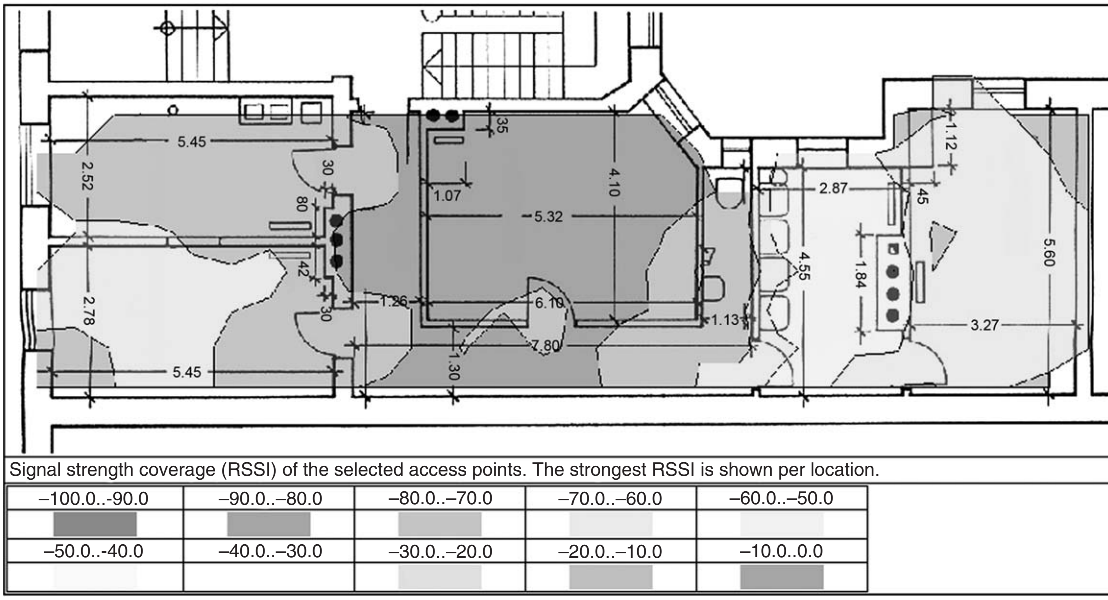

Figure 3 Signal strength (%) in the office area

Technical evaluation

Signal strength and signal-to-noise ratio were analysed with special software (Ekahau Site survey 2.1, Ekahau Inc., Helsinki, Finland). Signal strength in the areas of interest (office floors) is shown in Figure 3.

Since delay is one of the most disturbing factors in live video communication, the delays were measured from the source in the operating room to the hand-held device via the WLAN. To determine the delay, a wireless access point was temporarily established in the operating room, creating a local loop. A videotape with an integrated time code was used as a source and streamed to the hand-held client. Both video screens (input to and output from the hand-held device) were recorded with a separate digital video camera for subsequent analysis. The distance from the access point to the hand-held device was extended in 2 m steps. This enabled us to detect whether the system lost frames or hung when the signal quality and thus connection speed of the wireless network was decreased.

Clinical evaluation

To our knowledge, no standardized tool is available to assess objectively the suitability of video communication procedures in clinical surgery. Therefore, a new approach was developed in order to test a surgeon's ability to recognize typical operating room scenarios and anatomical structures.

Audio communication

The quality of voice transmission was assessed using test sets. Both the surgeon in the operating room and the remote consultant were asked to report with an established audio link 50 randomly generated numbers between 100 and 1000, as well as 20 pre-defined medical terms. At the two locations, an independent reviewer recorded whether the numbers and the terms were correctly identified.

Video transmission

The task was to identify important anatomical structures such as the recurrent nerve during re-section of a Zenker's diverticulum or the cystic artery during laparoscopic cholecystectomy. In open surgery, tasks like the recognition of the carotid artery during dissection of the cervical oesophagus or the identification of the internal inguinal hernia ring in hernia repair were selected (Table 1). A situation similar to an intraoperative consultation was created.

The original video clips were first reviewed by five experienced surgeons (consultants), who did not take part in the evaluation study. All scenarios appeared to them easily recognizable. The original video clips were then transmitted to the hand-held device. Each participant had to decide what had been demonstrated within 20 s of the end of the scenario. The quality and speed of recognition were determined using a scoring system ranging from 0 (no recognition) to 3 points (immediate, precise identification of the scenario and anatomical structures). Immediately afterwards, each participant had to identify the same sequence on a standard laparoscopic video screen. The quality of recognition was determined in the same way.

Table 1 Intraoperative scenarios for visual evaluation

	Scenario	Key finding/procedure
Oesophagoscopy	Endoscopic view of an oesophageal clip	Identification of clip
Laparoscopic view of the upper abdomen	Reduction of a para-oesophageal hernia	Para-oesophageal hernia
Laparoscopic ultrasonography	Ultrasound of liver	Recognition of liver cirrhosis
Laparoscopic cholecystectomy	Positioning of clips on the cystic duct	Identification of the triangle of Calot
Laparoscopic exploration of the left upper quadrant	Examination of the spleen	Detection of a splenic cyst
Endoscopy of the stomach	Anterograde inspection of a submucosal tumour	Identification of the tumour site
Thoracoscopy	Oesophageal dissection	Identification of a leiomyoma
Laparoscopic fundoplication	Laparoscopic dissection of the hiatus	Identification of oesophagus and cardia
Laparoscopic wedge resection	View of the stomach and surrounding organs	Identification of stomach and left liver lobe
Extended diagnostic laparoscopy	Peritoneal spread of a gastric cancer	Identification of peritoneal tumour seeds
Laparoscopic appendectomy	Dissection of the mesappendix	Identification of the appendix and the colon
Exploration of the pelvis	Examination of the adnexes and the uterus	Recognition of a myoma
Herniotomy	Dissection of the hernia sac	Identification of the internal hernia ring
Dissection of the cervical oesophagus	Cervical anastomosis	Identification of carotid artery and cervical anastomosis
Merendino's procedure	Anastomosis between stomach and small bowel	Identification of small intestine and gastric remnant
Small bowel resection	Skeletonization of the mesenterium	Recognition of vascular pedicle
Incision of the small bowel	Dissection of the antimesenterior of the jejunum	Identification of the small bowel
Preparation of a pedicled jejunal substitute	Closure of the mesenterial windows after anastomosis	Localization of the anastomosis
Re-section of a Zenker's diverticulum	Mobilization of the diverticular sac	Identification of recurrent nerve
Radiofrequency ablation of the liver	Laparoscopic ultrasound of the liver for positioning of the probe	Identification of tumour and recognition of the tip of the probe

Finally, a second sequence of video clips (sequence B) depicting the same (but not identical) surgical situations as described in Table 1, but from different patients, was presented in different order. A free dialogue was possible between the surgeon in the operating room and the test person using the hand-held device. The surgeon explained briefly the operative site. Then the test person was asked to identify the key structure.

Each of the groups consisted of 20 test persons. The training level of the surgeons in both groups was similar, each with 12 qualified surgeons and eight surgeons between the second and the fourth year of training.

Results

Connection to the wireless network was always possible without any problems in the areas covered by the access points. Analysis of the connection protocols showed one unauthorized computer which unsuccessfully tried to connect to the network.

At the end of the covered WLAN area, the connection speed to the first access point was 11 Mbit/s within a range of 11 m. At a distance of 11–14 m to the access point, connection speed was decreased to 5.5 Mbit/s and at 14–16 m the speed without connection problems was reduced to 2 Mbit/s (Figure 4). These values were mapped with direct sight to the access point without any attenuating elements (doors or walls) in between the client and the access point.

Moving through the WLAN-covered area was possible without any connection losses to the streaming server. The live video was always visible without interruptions. Comparison of the live video and the hand-held device connected to the streaming server via the WLAN showed a time shift of eight frames only.

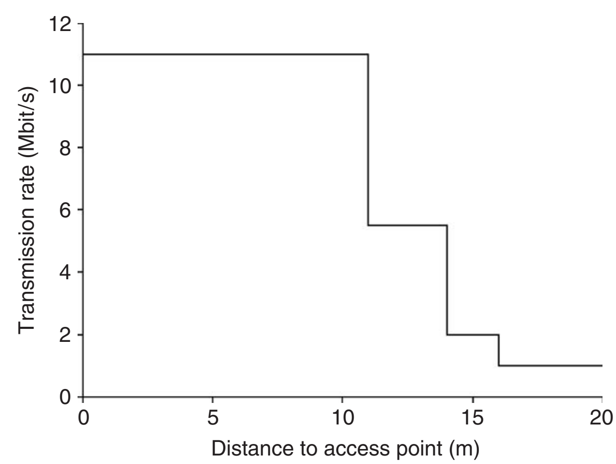

Figure 4 Decreasing transmission rate with increased distance to the access point

Clinical evaluation

Voice transmission

Correct understanding of numbers was achieved in 100% of the cases ($n = 1000$). Medical terms were understood precisely in 98% (range 90–100%) of the instances ($n = 400$). Again, the results were similar in each of the groups.

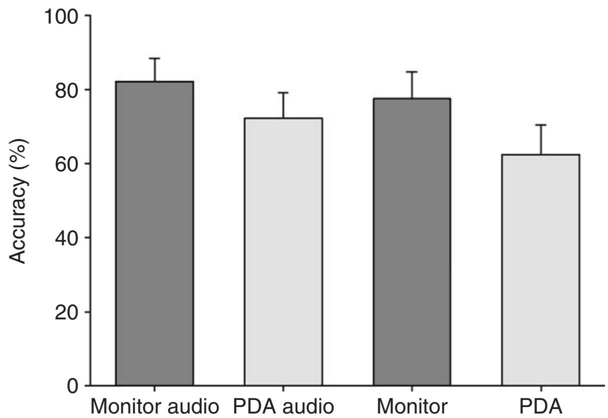

Figure 5 Accuracy of recognition of surgical scenarios (±SD): monitor audio: large video screen with vocal communication; PDA audio: hand-held device with vocal communication; monitor: large video screen (Mute); PDA: hand-held device (mute). Significance: monitor audio versus PDA audio: $P<0.001$; monitor (mute) versus PDA (mute): $P<0.001$

Video transmission

The precise recognition of specific scenarios of surgical interventions without verbal comments on the hand-held device was low. Only 62% (SD 17) of the structures were identified clearly on the hand-held device ($n=400$). The accuracy improved to 78% (SD 15) ($n=400$) if the same scenario was observed on a larger (50 cm) video screen ($P<0.001$). In contrast, accuracy was significantly better if audio conversation was possible. The results achieved with the hand-held device were nearly equal to those obtained by watching the video screen (Figure 5).

The video quality assessment showed that 72% (SD 15) of the key structures were identified clearly ($n=400$). Nevertheless, teleconsultation with the large monitor and audio connection showed a higher accuracy, with 82% (SD 13) correct findings ($P<0.001$) ($n=400$).

Technically, establishing oral communication with the audio software from the hand-held device to the software installed in the operating room was always possible. The speech quality evaluated by 20 surgeons was found sufficient in all cases, although six surgeons were dissatisfied with the audio delay and the resulting interruption in communication.

Discussion

Mobile telecommunication is increasing in importance in medicine.[8] Even though a wide field of applications has been described,[9] very few reports are available about mobile broadcasting of surgical operations.[6,10] Almost all of these applications are for educational purposes. However, mobile teleconsultation using a hand-held device could be particularly valuable for surgical teleconsultation as well. This was pointed out by Banitsas *et al.*,[4] who evaluated the use of hand-held devices for real-time wireless teleconsultation. They assessed the communication quality of still images and of videoconferencing but, to our knowledge, not of surgical operations. Since little is known about the adequacy and suitability of mobile teleconsultation under real clinical conditions, we evaluated mobile teleconsultation in a realistic surgical setting.

It is comparatively easy to assess the technical accuracy and reliability of a communication system, but medical – or clinical – test procedures have not been available until now. In most studies, more or less subjective scoring systems or questionnaires are used to assess the opinion of the users about the quality of data transmission.[1,11,12] Although the methodology of these subjective ratings has been significantly refined with the introduction of the Absolute Category Rating,[13,14] which is still frequently used,[15] there are no standardized tools to assess the objective effect of audiovisual communication. Therefore, we created a new test set depicting 20 different video segments of surgical intervention. All of them demonstrated a characteristic part of a well-defined surgical operation which should be easily recognized by an average surgeon. They were presented to test persons either on the small screen of the hand-held device or on a normal screen as used in conventional telecommunications. In addition, the recognition was assessed with or without vocal communication. Self-evidently, this test scenario is less than ideal, since a learning effect may occur as soon as the video segment is demonstrated once again. To reduce this effect, no comment was made about the decision until the test was finished. The results showed, as expected, that the recognition rate was lower using the personal digital assistant (PDA), both with and without oral communication. The difference was lower in test persons with a particularly high surgical training level, but not significant.

However, even if the 'normal' teleconsultation monitor and vocal communication were provided, the recognition rate was about 80%. Obviously, it is not easy – even for expert surgeons – to interpret quickly specific segments of surgical operations if they are presented in a random order (e.g. laparoscopic, open/conventional). Thus, our test model offers the required power of discrimination. Although the rate of identification will certainly not be 100%, it is, nevertheless, useful to reflect the quality of transmission. The present study showed conclusively that oral communication improves the recognition rate, both on the small PDA display as well as on the large monitor. However, the visual information on a PDA is still inferior to the full display on a standard monitor.

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