

Development of a Telediagnosis Endoscopy System over Secure Internet

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Summary

Objectives: We developed a new telediagnosis system to securely transmit high-quality endoscopic moving images over the Internet in real time. This system would enable collaboration between physicians seeking advice from endoscopists separated by long distances, to facilitate diagnosis.

Methods: We adapted a new type of digital video streaming system (DVTS) to our teleendoscopic diagnosis system. To investigate its feasibility, we conducted a two-step experiment. A basic experiment was first conducted to transmit endoscopic video images between hospitals using a plain DVTS. After investigating the practical usability, we incorporated a secure and reliable communication function into the system, by equipping DVTS with "TCP2", a new security technology that establishes secure communication in the transport layer. The second experiment involved international transmission of teleendoscopic image between Hawaii and Japan using the improved system.

Results: In both the experiments, no serious transmission delay was observed to disturb physicians' communications and, after subjective evaluation by endoscopists, the diagnostic qualities of the images were found to be adequate. Moreover, the second experiment showed that "TCP2-equipped DVTS" successfully executed high-quality secure image transmission over a long distance network.

Conclusions: We conclude that DVTS technology would be promising for teleendoscopic diagnosis. It was also shown that a high quality, secure teleendoscopic diagnosis system can be developed by equipping DVTS with TCP2.

Keywords

Telemedicine, remote consultation, videoconferencing, endoscopy, computer security

Methods Inf Med 2008; 47: 157–166

doi:10.3414/ME0488

1. Introduction

Telemedicine is expected to improve health-care in regions where access to good medical care is limited due to geographical disparity or unavailability of appropriate medical specialists. In conventional telemedicine, only still images such as X-rays, various kinds of computerized tomography, and pathological microscopy have been transmitted due to limitations in the communication capacity of networks. However, owing to recent advances in broadband communication, it is now possible to transmit high-definition moving images over the Internet. Medically relevant moving images such as ultrasound or endoscopic images are transmitted in real time with ordinary equipment such as internet-connected PCs and digital video (DV) cameras used in standard teleconferences.

In this study, we developed a new telediagnosis system, which can transmit fine moving endoscopic images securely over the Internet in real time. Since endoscopic diagnosis requires years of experience and special skills, it is desirable for general physicians to receive advice from experienced endoscopists, especially for difficult diagnostic cases. The purpose of this system is to facilitate collaboration between general physicians and experienced endoscopists, who are separated by long distances. With the use of a teleendoscopic diagnosis system, general physicians can consult the endoscopists in real time.

We utilized a new type of digital video streaming system, Digital Video Transport System (DVTS) [1], for our teleendoscopic image transmission. DVTS is now widely used for teleconferences [2], and is expected

to be successfully applied in the field of medicine to enable high-definition image communication.

To investigate the feasibility of the DVTS-based telediagnostic system, we conducted a two-step experiment. First, we conducted a basic experiment, in which endoscopic images were transmitted using a plain DVTS between hospitals 20 km apart. In this experiment, the diagnostic quality of the transmitted images was extensively evaluated with regard to whether the DVTS system could be used for real-time teleendoscopic diagnosis.

The evaluation was conducted in three ways. First, two endoscopists participating in the teleendoscopic experiment were asked to evaluate, in detail, the diagnostic quality of the transmitted endoscopic images after finishing the online transmission experiment. Second, to obtain more objective evaluation results, we increased the number of endoscopists to 10, and conducted a post-experiment evaluation using video-recorded original and transmitted images. In the second evaluation, subjective assessment of the transmitted images by the 5-scale rating method was followed by evaluation using the Double Stimulus Continuous Quality Scale (DSCQS) [3], which is a well-established method for comparing images. Examiners were shown pairs of original and transmitted images alternately for a duration of 10 seconds. This sequence was repeated twice, and the degree of degradation between the images was evaluated. Finally, we conducted the DSCQS evaluation using an automatic image comparison device to complement the above DSCQS evaluation by endoscopists and attain objective results.

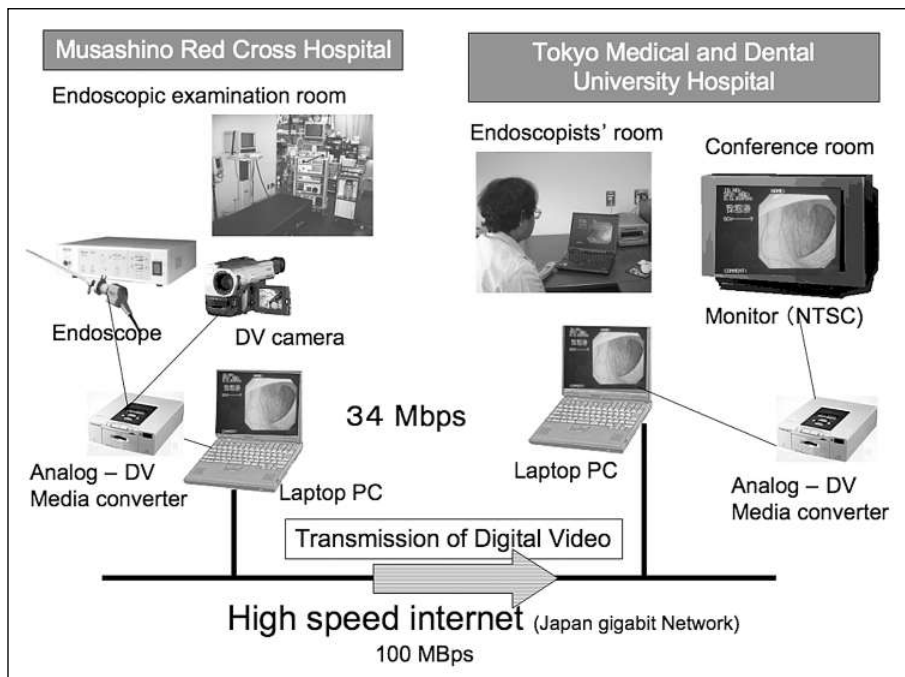


Fig. 1 System configuration of teleendoscopic experiment

After investigating the possibility of practical usability of this DVTS-based teliagnosis system, we incorporated a secure and reliable communication function into it, because these functions are essential in medical applications.

In relation to the security of image transmission, DVTS by itself cannot perform secure communication. As one of the methods to develop secure communication in DVTS, we installed "TCP2" [4]. This is a new security technology that enables secure communication in the transport layer of the network. TCP2 also has a retransmission function that resends packets on the user datagram protocol (UDP) layer to ensure data reliability if packets are lost in the communication. This function would be useful for attaining high fidelity in image transmission, which is another crucial issue in medical image communication.

Considering the advantages of TCP2, we developed a new secure teleendoscopic diagnosis system using "TCP2-equipped DVTS" and conducted the second experiment, where we transmitted colonoscopic images between the University of Hawaii (UH) and Tokyo Medical and Dental University (TMDU) to observe the perform-

ance of the newly developed secure DVTS in a long distance network. We investigated the quality and security of this teleendoscopic experiment, and discussed the practical usability of the teleendoscopic diagnosis system.

2. Methods

2.1 Basic Teleendoscopic Experiment Using DVTS

DVTS is a new high-quality streaming technology, which enables transmission of a DV stream over the Internet. This system has been released as free software [1, 2] and is now widely used for general-purpose teleconferencing. In DVTS, DV data are sent by the UDP using RTP (real-time transportation protocol). The real-time stream packets of DV are simply encapsulated with RTP/UDP/IP; hence, attached with the RTP/UDP/IP headers. Using this DVTS system, the video data can be transmitted without any inter-frame compression like that in MPG1 and MPG2, resulting in high-quality image transmission. Moreover, with DVTS,

users can transmit a real-time video stream with minimum equipment, e.g., internet-connected notebook PCs and DV cameras that are connected to the PC using IEEE1394 for sending lossless DV images. The necessary bandwidth for sending full frame rate (30 frames/sec) images is 35 Mbps. When the bandwidth of the network is lower than this, DVTS can reduce the frame rate (less than 30 frames/sec) to fit the bandwidth.

As the first step to examine the feasibility of the application of DVTS for teleendoscopic diagnosis, we conducted real-time teliagnosis experiments whereby general physicians manipulating the endoscope in one hospital consulted the experienced endoscopists in another remote hospital. The participating hospitals were Musashino Red Cross Hospital and TMDU's hospital, which are 20 km apart in Tokyo. Colonoscopic images were adopted as the transmitted endoscopic images. Figure 1 shows the experimental system configuration. The endoscopic images were transmitted through high-speed Internet, the Japan Gigabit Network (JGN) [5], between the two hospitals. The equipment used in the experiments is shown in Table 1. We used two computers connected to a DV camera, which contained the necessary DVTS software. The bandwidth of the network used was 100 Mbps. The resolution of the transmitted images was set to 780×480 pixels and RGB was 32 bit. Using DVTS, we transmitted four patients' colonoscopic images from the endoscopic examination room in Musashino Red Cross Hospital to TMDU's hospital. We measured performance indexes such as packet loss rate, transmission delays, bandwidth occupied by streaming, and CPU occupation rate.

2.2 Quality Evaluation of Teleendoscopic Images

The evaluation of the quality of transmitted images is very important for telemedical studies. We conducted extensive evaluation studies on the quality of transmitted images in this basic teleendoscopic experiment using a plain DVTS. Evaluation was executed in three ways: first is a detailed

qualitative assessment by two endoscopists with more than 20 years clinical experience, who participated in the tediagnosis experiment; second is the post-experiment evaluation by an increased number of endoscopists, each having eight years clinical experience on average; and the third is an evaluation using an automatic image comparison device. Both, the second and third evaluations used the video-recorded original and transmitted images from the basic experiment.

2.2.1 Qualitative Detailed Evaluation by the Experienced Endoscopists Participating in the Tediagnosis Experiment

During a teleendoscopic online experiment, two experienced endoscopists in TMDU's hospital viewed and diagnosed the actual video of the colon in real time. While they were diagnosing the transmitted images, they could communicate with the physician who actually conducted the endoscopic examination in the Musashino Red Cross hospital. After the tediagnosis experiment, they were asked to evaluate the diagnostic ability of the transmitted images on the tediagnosis system. The evaluation was done by detailed qualitative specialists' assessment of the transmitted endoscopic images. Two kinds of monitors were used in this evaluation; one was a laptop computer screen (with DVTS installed) and the second was a NTCS TV monitor used for ordinary endoscopy.

2.2.2 Post-experiment Evaluation by Increased Number of Endoscopists

After finishing the teleendoscopic experiments, to obtain a more objective evaluation we increased the number of endoscopists to 10. We conducted the post-experiment evaluation using the recorded transmitted images received at TMDU's hospital. The original and transmitted images in the basic experiment were digital; hence, their video-recorded images did not undergo degradation. The examiners were asked to evaluate the diagnostic ability of the transmitted endoscopic images on a 5-point scale: 5 (excellent), 4 (good), 3 (fair), 2 (poor), and 1

Table 1
Equipment used in the basic experiment

Equipment	Model	Specifications
Client PC in Musashino Red Cross Hospital (Sending)	IBM ThinkPad T23	Pentium3/CPU: 866 MHz/Memory: 256 MB Built-in IEEE 10/100 Base-TX Ethernet
Client PC in TMDU (Receiving)	IBM ThinkPad X23	Pentium 3/CPU: 1 GHz/Memory: 512 MB Built-in IEEE 10/100 Base-TX Ethernet
DV camera	DV CAM DSR-20	Digital i.LINK (IEEE1394 compliance)

(bad) with respect to three items, quality of color tone, morphological clearness, and diagnosability. Evaluation was done on the screen of the laptop PC.

We also conducted an evaluation using DSCQS to examine the degree of degradation between images. We used it to compare the original and transmitted endoscopic images. In this method, examiners were shown a pair of images (original and transmitted moving image) alternately for a duration of 10 seconds. They were not informed of which image was the original one. The procedure was repeated twice, and they were asked to evaluate the degree of image degradation. This method has been standardized by the ITU (International Telecommunication Union; ITU-R BT.500-7 [3, 6]), and the quality of moving images is rated from 0% to 100%, where 0% means no degradation and larger scores mean more degradation.

2.2.3 Post-experiment Evaluation Using the Automatic Picture Quality Assessment System

DSCQS is a reliable quality assessment technique. However, in practice, more than

15 examiners are recommended by the ITU to participate in the evaluation for obtaining reliable results. It is ordinarily difficult to enlist more than 15 endoscopists. In our experiment, 10 endoscopists participated in the evaluation. To complement the lack of examiners for the original DSCQS method, we additionally conducted image comparison using an automatic picture quality assessment system (VP21S, K-Will corporation, California) [7].

This equipment receives images from the source and destination on the NTSC monitor and automatically detects the delay and degradation between the two moving images. The results from this system showed high correspondence with the subjective assessment done by the DSCQS method, and can be used to complement the results of the DSCQS method. The equipment used was the picture quality assessment system (VP21S; described above) and two videocassette recorders (DSR-20, ESR-30; SONY). The screen shot of the picture quality assessment system is shown in Figure 2. According to ITU-R's recommended guidelines, the permissible range of the DSCQS values in the broadcast system should be less than 12% [6].



Fig. 2 Captured sample images of the picture quality assessment system and the DSCQS assessment system's equipment

Table 2 Equipment for tele-endoscopic experiment in the international network

Equipment	Model	OS	Specifications
Client PC in TMDU (Sending)	Mouse Computer	Windows XP	CPU: Pentium4 (3.0 GHz)/Memory: 1024 MB
Client PC in UH (Receiving)	IBM/M50	Windows XP	CPU: Pentium4 (3.0 GHz)/Memory: 512 MB
DV camera	SONY/DCR-PC300K		Digital i Link (IEEE1394 compliance)

Table 3 Results of the experimental system performance evaluation (between TMDU and Musashino Red Cross Hospital). Results of the experiment are summarized in this table. Quality of images: excellent or a few block noises sometimes appear.

Evaluation of Experiment	TCP Throughput Average (Mbps)	TCP Packet Loss (%)	Quality		CPU Occupation Rate (%)	Delay (sec)
			Video (Block noise)	Sound		
DVTS	34.65	0.03	Rarely appear	Clear	37–40	0.1–0.2

2.3 Experiment on the High-quality Secure Transmission of DVTS-based Teleendoscopy

2.3.1 Adoption of TCP2 for Secure Transmission

DVTS itself does not have a secure communication function. We upgraded our tele-endoscopic diagnosis system by incorporating security functions using encryption technology. To do this, we adopted a new secure technology named TCP2 [4]. Since TCP2 (developed by TTT Co. [8]) is a new technology, we explain it here in brief.

TCP2 is the security technology that enables us to encrypt data, exchange keys, and execute authentication in the transport layer (OSI fourth layer). TCP2 works at the lower transport layer, in contrast to SSL that works in the session layer and IPsec that works in the network layer [9]. Thus, it has several advantages. Although SSL is considered weak against attacks to the lower layers, TCP2 is robust to them. IPsec cannot be used in networks where IP addresses are dynamically changing, as firewall settings have to be changed to pass through the IPsec protocol. However, in case of TCP2, it is not necessary to change the settings in any network environment.

TCP2 is equipped with TCP, TCPsec, UDP, UDPsec, IP, ICMP (Internet Control Message Protocol), and IGMP (Internet

Group Management Protocol) (Fig. 3) and consists of two emulators, TCP2 and UDP. Each emulator provides encryption onto the TCP and UDP, respectively, as well as conventional functions. All kinds of encryption algorithms like AES, 3DES can be implemented. When a sender transmits data with TCP2, only a receiver installed with TCP2 can start an encrypted communication with TCPsec. If a sender transmits data with TCP, the receiver communicates with ordinary TCP or cut-off connections. The receiver with TCP2 can avoid unauthorized access by limiting communication of TCPsec packets.

2.3.2 Teleendoscopic Experiments Using the International Network

For the second experiment, we conducted international teliagnosis of endoscopic images with TCP2-equipped DVTS between Hawaii and Japan over the Asia-Pacific Advanced Network (APAN) [10]. The bandwidth of APAN is 156 Mbps. We transmitted endoscopic images from the UH to TMDU in real time. The experimental equipment is shown in Table 2. Audio streams were also simultaneously transmitted over the same network. The video stream was transmitted without compression at the rate of 30 frames per second. We tracked the route that these packets followed using the trace route command at the Windows command prompt. During this

streaming, we also observed the quality of transmitted video and audio data. We examined them under the two conditions: plain DVTS and TCP2-equipped DVTS.

In order to compare the results with the first experiment, we did not arrange a real clinical experimental setting for the second experiment. Instead, the colonoscopic images recorded by the original endoscopic equipment at the sender hospital in the first experiment were used as moving endoscopic images to be transmitted. In the second experiment, unlike the first one, they were transmitted through the international network with the improved DVTS.

3. Results

3.1 Results of the Basic and Evaluation Experiments for the Teleendoscopic Diagnosis System

The experimental results of system performance indexes are shown in Table 3. The result of the packet loss was only 0.03% and degradation in the image quality was not observed. The delay was 0.1–0.2 seconds and it did not interrupt physicians' communication in this experiment.

The results of subjective assessments by two experienced endoscopists are shown in Table 4. The endoscopic findings were mostly same between the two endoscopists except for the consolidation in Crohn's disease (cases 1, 2) and redness and friability of the mucosa in nonspecific colitis (case 3). To investigate validity of the teleendoscopic diagnosis, we confirmed the exact diagnoses for all the cases by other clinical and pathological examinations such as blood test or biopsy.

Comparing with exact diagnosis of the examined patients, two endoscopists, based on the transmitted endoscopic images, could correctly diagnose all the cases except case 3, which was considered nonspecific colitis and found to be diagnostically difficult even with the original colonoscopy, because by its nature, this case was difficult to diagnose using only colonoscopy.

The post-experiment evaluations by 10 endoscopists are shown in Table 5. They

Table 4 Results of the qualitative detailed evaluation by the experienced endoscopists. This table summarizes the results of diagnostic evaluation by two experienced endoscopists. Quality of image and color tone is described in free text and in tabulating these items we put together two endoscopists' comments. (+): The diagnostic findings were observed by the transmitted endoscopic image. (–): The diagnostic findings were not observed.

Diagnosis and diagnostic findings	Endoscopist 1	Endoscopist 2	Quality of image	Diagnosability
Case 1: Diagnosis	Crohn's disease	Crohn's disease		
Cobblestone appearance	(+)	(+)	Sharp image No color's saturation No blur	Although the image on PC screen wholly seemed a little white on the whole, it was possible to make the exact diagnosis. TV monitor was suitable for tele-diagnosis. Diagnosability was very high.
Longitudinal ulcer	(+)	(+)		
Skip lesion	(+)	(+)		
Narrowing of colon lumen	(+)	(+)		
Consolidation	(+)	(–)		
Case 2: Diagnosis	Crohn's disease	Crohn's disease		
Cobblestone appearance	(–)	(–)	Sharp image No color's saturation No blur	TV monitor color tone was yellow-tinged. It was little difficult to find hemorrhage of mucosa. This was a mild case, therefore diagnostic findings were not very clear, but enough to diagnose.
Longitudinal ulcer	(+)	(+) Small		
Skip lesion	(+)	(+)		
Narrowing of colon lumen	(–)	(–)		
Consolidation	(+)	(–)		
Case 3: Diagnosis	Ulcerative colitis	Nonspecific colitis		
Loss of the vascular patterns of the colon	(+)	(+)	Magnifying endoscopy image was blur of red color	It was difficult to diagnose because of inadequate pre-treatment. TV monitor was yellow-tinged. Chromo and magnifying endoscopy were useful for diagnosis.
Redness of the mucosa and friability of the mucosa	(+)	(–)		
Pseudopolyps	(–)	(–)		
Diffuse superficial ulceration	(+)	(–)		
Lead pipe appearance of the colon	(–)	(–)		
Case 4: Diagnosis	Ulcerative colitis	Ulcerative colitis		
Loss of the vascular patterns of the colonic mucosa	(+)	(+)	Sharp image No color's saturation No blur	It was difficult to recognize subtle color variation. This was a severe case. Diagnostic findings were specific, therefore this case was easy to diagnose.
Redness of the mucosa and friability of the mucosa	(+)	(+)		
Pseudopolyps	(+)	(+)		
Diffuse superficial ulceration	(+)	(+)		
Lead pipe appearance of the colon	(+)	(+)		

evaluated the diagnostic quality of the transmitted images by rating them on the following scale: 5 (excellent), 4 (good), 3 (fair), 2 (poor), and 1 (bad). The judgment of diagnostic quality of teleendoscopic images was obtained by the average of the evaluation score of each item. The average score of each item was 3.9 in color tone, 4.4 in morphological clearness, and 4.3 in diagnosability. Although the evaluation in color tone was relatively low, the total average over the three items is 4.2, which is intermediate between excellent and good. Thus, it could be concluded that the image quality of this teliendoscopic system would be sufficient for diagnostic use.

The results of evaluation using the DSCQS method by 10 endoscopists are

shown in Table 6. All of the DSCQS results were within 5% degradation between the original and transmitted images, with that of one case (case 1) being 0% (no degradation). This meant that the degradation of the teleendoscopic image is so low in its percentage that it could not be detected by human eyes. Thus, we can say that all the 10 examiners evaluated the teleendoscopic images as usable in a clinical situation, though it showed very little degradation. Moreover, Figure 4 shows the results of the automatic quality assessment system, where the X-axis is frame number with the rate of 30 frames/sec, and the Y-axis shows the DSCQS values described in percentage. Proportion of frames where DSCQS was less than 12% is 79.3%, though sometimes

there was infinitesimal noise, blurring, and block noise due to packet loss. This confirmed that the quality of images in the teleendoscopic system was adequate for diagnosis of, at least, the experimental cases.

3.2 Results of the Experiment in the International Network

Table 7 shows results of the second experiment. The colonoscopic images transmitted between UH and TMDU were of sufficiently good quality as with the former basic teleendoscopic experiment. With this long distance experiment, the number of hops in the network from TMDU to UH was five. Round trip time (RTT) was 78 ms.

Table 5 Results of the post-experiment evaluation by the endoscopists. This table summarizes the results of subjective evaluation by 10 endoscopists. Evaluation scales are 5 (excellent), 4 (good), 3 (fair), 2 (poor), and 1 (bad).

	Examiners	A	B	C	D	E	F	G	H	I	K	Mean Value
Case 1	Color	4	4	4	5	4	3	3	5	4	4	4.0
	Morphology	5	4	5	5	4	4	4	5	4	5	4.5
	Diagnosability	5	4	5	5	4	4	4	5	4	5	4.5
Case 2	Color	3	4	3	5	5	3	3	4	4	4	3.8
	Morphology	4	4	5	5	5	4	4	5	4	4	4.4
	Diagnosability	4	4	5	5	5	4	4	5	4	5	4.5
Case 3	Color	3	4	3	5	5	4	4	5	3	4	4.0
	Morphology	4	4	5	5	5	4	4	5	4	4	4.4
	Diagnosability	4	4	4	3	5	4	4	5	4	3	4.0
Case 4	Color	4	4	4	5	4	3	4	4	3	4	3.9
	Morphology	5	4	5	5	4	3	4	5	4	4	4.3
	Diagnosability	5	4	5	4	4	4	3	5	4	4	4.2
All cases	Color											3.9
	Morphology											4.4
	Diagnosability											4.3

Table 6 Results of the subjective assessment by the DSCQS method. This table summarizes the results of subjective assessments by 10 endoscopists. Evaluation scales are 0 to 100(%).

Examiners	A	B	C	D	E	F	G	H	I	J	DSCQS Arithmetic mean (%)
Case 1	0	0	0	0	0	0	0	0	0	0	0
Case 2	0	20	0	0	20	0	0	0	0	0	4
Case 3	20	0	0	0	0	0	0	0	0	20	4
Case 4	20	0	0	0	0	0	0	0	0	0	2

Throughput of TCP2-equipped DVTS was 51.48 Mbps. Although it was lower than the results in the DVTS without TCP2 (69.59 Mbps), it was considered sufficient because it exceeded the necessary bandwidth required for sending full-frame rate video by DVTS (35 Mbps).

The results of the experiment using DVTS without TCP2 showed packet losses were 3.7% and block noises caused by packet losses were rarely observed. In contrast to this, packet losses and block noise were actually none in TCP2-equipped DVTS, as shown in Table 7. The retransmission function of TCP2 was effective on the UDP in the transmission experiment over APAN, so there was no packet loss with TCP2-equipped DVTS. The CPU occu-

pation rate of the system with TCP2 was higher than without TCP2 because it needed high CPU power for encrypting data in real-time. Figure 5 shows a sample of captured real image of the transmitted video.

Concerning the quality of transmitted images, no influence of using encryption technology was seen. The results showed that TCP2-equipped DVTS provides sufficient performance for high-quality secure image transmission even in large RTT (round trip time) environment. Our experiments also showed that, even with the UDP that does not have retransmission functions, if augmented by TCP2, it was possible to establish secure communication and ensure the quality of real-time streaming.

4. Discussion

With the development of broadband Internet technology such as high-speed networks or video streaming systems, telemedicine with the transmission of diagnostic images has moved from the use of still images of X-rays and photographs [11] to that of moving images such as echocardiography [12], dermatology [13], microscopy [14], and endoscopy. As for tele-endoscopy, early experiments were mostly conducted by transmitting snapshot images selected from the endoscopic video stream [15]. Early experiments tried to transmit moving endoscopic images using telephone lines with image compression, but detailed diagnosis was difficult using these transmitted images [16, 17]. The subsequent teleendoscopic experiments using ATM lines with compressed images (MPG2) attained good performance in terms of quality, but the loss of images was observed by endoscopists [18, 19].

In our study, we took advantage of the broadband network and developed the teleendoscopic diagnosis system to transmit high-quality moving images using the DVTS image transmission system. To evaluate the feasibility of our telediagnosis system, we conducted a two-step experiment. The first basic experiment revealed that we successfully constructed a high-quality teleendoscopic diagnosis system using DVTS. This transmits high-quality images with less transmission delay and is inexpensive and easy to construct using only consumer equipment.

For the evaluation of the quality of the transmitted endoscopic images, we conducted three kinds of image evaluations. In the first subjective evaluation by two experienced endoscopists, most detailed endoscopic findings, except for nonspecific colitis, were mostly agreed between the two endoscopists. It was clear from the basic telediagnostic experiment that this system had sufficient quality to diagnose colon diseases and could support colonoscopic telediagnosis.

In the subjective assessment of the image quality by 10 endoscopists, we obtained total average score of 4.2, which is intermediate between "excellent" and "good" on the 5-scale rating. This score indicates that

the teleendoscopic diagnosis system is sufficient to diagnose the colon diseases correctly. Thus, we reached the same conclusion even when we increased the number of evaluators and used quantitative scores for image evaluation.

Furthermore, we also conducted the evaluation on the quality of endoscopic images using the DSCQS method for subjective assessment, by 10 examiners. From the results shown in Table 6, the average of the DSCQS by the subjective evaluation was 2.5%. This means that the degradation was so indiscernible that by human eyes the original and transmitted endoscopic images were identical.

Finally, we conducted the evaluation using a picture quality assessment system. DSCQS values obtained by the picture quality assessment system were mostly less than 10%. These were less than 12%, which is the limit for good-quality image level as recommended by ITU-R.

Several peaks of DSCQS were observed in the assessment system. We estimated that these peaks were mainly due to accumulation of noise caused by limitation of CPU power in the processing of DVTS. We speculate that the DVTS software tried to correct delay by skipping images and this process requires a certain time period to recover synchronization, which induces high-valued peaks of DSCQS in the automatic picture quality assessment system.

Comparison of the results of the picture quality assessment system and subjective assessment by 10 endoscopists brings us to speculate that noise in DVTS invisible to human eyes might have considerable effects on the automatic picture quality assessment. We think suppression of noise would result in stability and better precision.

The persistent problem that we have to consider is color reconstruction in the transmitted endoscopic images. In the two experienced endoscopists' assessment of the diagnosability and also in the subjective evaluation by 10 endoscopists, the insufficiency related to color reconstruction was pointed out. The transmitted endoscopic images could not be technically duplicated in exactly the same quality as the original image. Even if the CPU speed and bandwidth were sufficient to encode the image

Fig. 3
Structure of TCP2

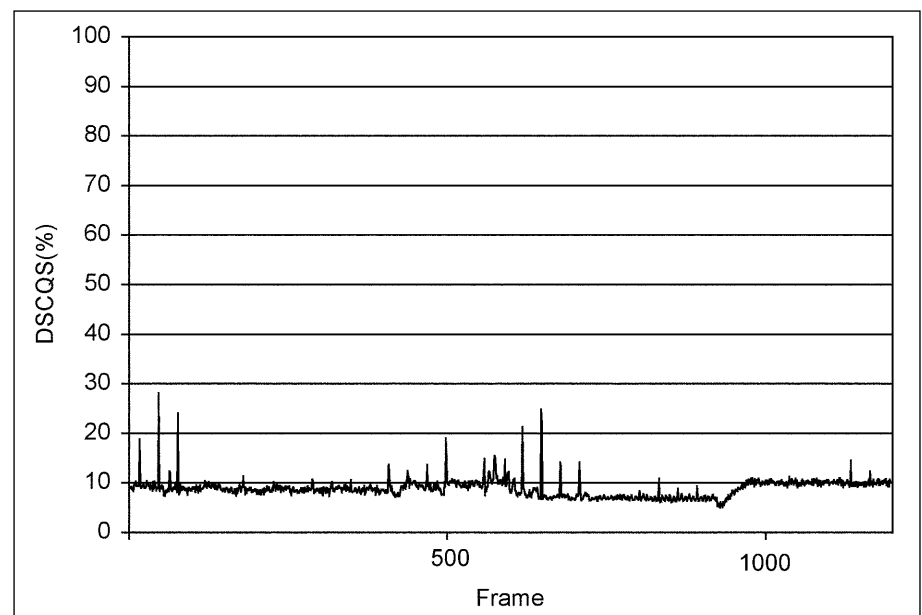
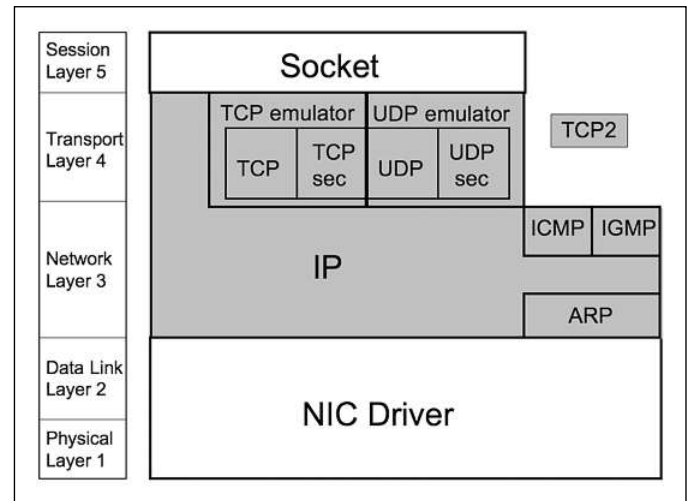


Fig. 4 The results of the DSCQS by the picture quality assessment system

without compression, there would still be differences in color reconstruction.

To attain complete reproducibility of colors in network-transmitted images, there

have been several pioneering studies. One of these is the "Natural vision project" carried out by Yamguchi et al. [20] where a new innovative video and still-image communi-

Table 7 Results of the experiment (between TMDU and UH). This table summarizes the results of the experiment in the international network (from Japan to Hawaii). These results show the data measured in UH.

Evaluation of Experiments	TCP Throughput Average (Mbps)	TCP Packet Loss	DVTS		CPU Occupation Rate (%)	Transmission on Delay (sec)
			Packet loss (/sec)	Quality of Image		
Without TCP2	69.593	3.7	1–7	Rarely appear	25–30	Rarely
With TCP2	51.484	0	0	Nothing	35–45	No Delay

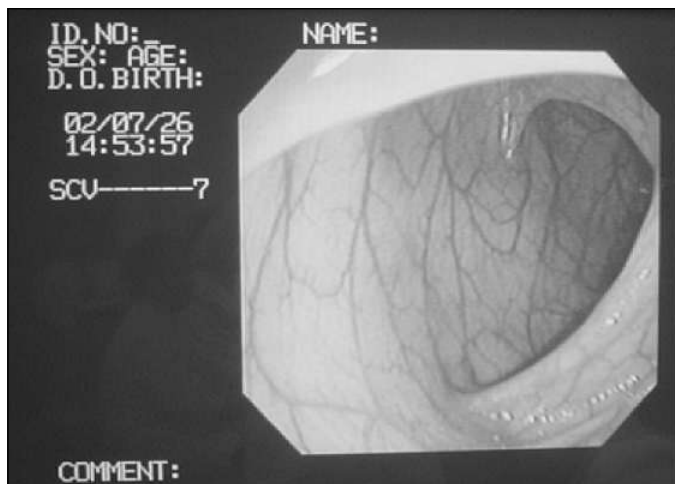


Fig. 5
Captured sample images
of the transmitted endo-
scopic video

cation technology with high-fidelity color reproduction capability was realized based on spectral information. Other than this trial, similar research using spectral decomposition has also been conducted by Miyake et al. [21] for color reproduction technology. However, currently, these methods are too costly to be implemented in the ordinary Internet environment and may be a part of the future solutions.

At present, more feasible solutions should be considered. In telediagnosis, though one of the purposes is to reconstruct the original images as exactly as possible, the goal is also to attain a level of 'diagnostic equivalency' between the transmitted image and the original image. From this point of view, several experiments have shown that our teleendoscopic diagnosis system has sufficiently high clinical feasibility because differences in monitor characteristics did not affect diagnostic equivalency too much. In practice, the selection of adequate monitors and color tuning for the telediagnosis system would compensate subtle differences and improve diagnostic quality further.

The problem that we have to consider next is the security of the telediagnosis system.

Since DVTS does not have security functions in the original version, we incorporated a secure communication function that is essential for medical applications. To do this, we chose a new security technology, named TCP2, which can encrypt the real-time transmitting video using DVTS at the

level of the transport layer. DVTS is developed based on the UDP for video streaming; hence, SSL technology cannot be employed for it. IPsec and TCP2 are able to encrypt on the UDP. If we employ IPsec, throughput of encrypted retransmitted packets is reduced in the unstable network in which many packet losses occur along with a lot of physical noise. TCP2 is robust in an unstable network because it incorporates resending of lost packets on the UDP. Thus, considering the above aspects, it is concluded that TCP2 would be the most suitable secure technology to be implemented into DVTS.

We conducted the international experiment over APAN to test this TCP2-equipped DVTS. This showed that even with a long-distance network between Japan and Hawaii, we could build a high-quality secure network with this improved DVTS. The necessary bandwidth for DVTS is 35 Mbps, which is sufficiently available to the typical home networks such as fiber-optics or ADSL networks of 100 Mbps. However, 100 Mbps is best-effort bandwidth and it is difficult to guarantee the necessary bandwidth for Internet using ordinary fiber-optics and ADSL. Therefore, we should consider the use of exclusive lines or bandwidth-guaranteed networks for medical use. As far as our experiment is concerned, we could ensure sufficient bandwidth due to use of the exclusive APAN line.

In addition, regarding technical problems with the TCP2-equipped DVTS, it should be noted that its CPU occupation rate was high because it needs high computer

power for encryption and decryption. Thus, in our experiment, only a unidirectional test was possible due to limitations of the computer because we used the note PC to demonstrate the feasibility of our telediagnosis systems. If other applications run during transmission of images with DVTS, the transmitted images might be distorted because of the lack of computer capability. In the future, when the processing speed of ordinary PCs becomes faster, the TCP2-equipped DVTS will be able to transmit images in bidirectional communication and execute multitasking. Once these problems are solved, the application of TCP2 technology will spread, promoting the establishment of secure medical networks.

According to the American Telemedicine Association [22], "telemedicine is the use of medical information exchanged from one site to another via electronic communications to improve patients' health status". Above all, they pointed out the importance of specialist referral services, which typically involve a specialist assisting a general practitioner in rendering a diagnosis [23]. This clearly coincides with the intention of developing our teleconsulting endoscopic system, which might have an extremely high feasibility rating for a clinical application.

There is another issue that is important for considering telemedicine applications; as stated in the following: "Some real-time telemedicine applications have been taken up with enthusiasm, even if formal evidence of cost effectiveness may be lacking" [24]. We think that most telemedicine systems are high cost. In contrast to the most of the telemedicine systems, our telediagnosis system is reasonably low cost, with internet-connected PC and DV cameras, so that it may substantially resolve the issue of telemedicine cost. We consider that it is one of the advantages of our telediagnosis system as compared with the others [25].

In conclusion, the feasibility of applying our telediagnosis system in a clinical setting has been demonstrated. Such a telediagnosis system will prevail more widely when high-speed broadband Internet becomes available among most of the medical institutions. Moreover HIMSS (Healthcare Information and Management System Society)'s white paper [26] said that "the application of

Internet and other related technologies in the health care industry” improves “the access, efficiency, effectiveness and quality of clinical care and business processes” [27]. We believe that our telediagnosis system could also be used for other medical applications such as teleconsultation between hospitals or home telehealthcare.

5. Conclusions

A basic telediagnosis endoscopic experiment using DVTS and an international teleendoscopic experiment using TCP2-equipped DVTS were conducted to investigate the feasibility of using DVTS-based teleendoscopic diagnosis over the Internet. It was shown that the transmitted endoscopic images were found to have very high diagnosability by the extensive evaluation examinations. Both systems worked well but in particular, the teleendoscopic diagnosis system using TCP2-equipped DVTS can execute high-quality secure moving image transmission even over a long distance network. Our telediagnosis system is easy to implement and use, and costs are low. From these points of view, this system would contribute to increase in collaboration between general physicians and experienced endoscopists for diagnosing difficult cases and help in improving the overall medical care.

Acknowledgments

We would like to express our sincere thanks to Dr David Lassner and Alan Whinery, University of Hawaii, for their support in our international experiment. We would also like to thank T.T.T Corporation for providing us with TCP2 implementation.

References

- DV (Digital Video) over IP (DVTS). WIDE project & DVTS Consortium; c2001–06 (updated 2006 April 27). Available from: <http://www.sfc.wide.ad.jp/DVTS/>.
- Sugiura K, Sakurada T, Ogawa A, Nakamura O, Nakagawa S, Murai S. DVTS using portable notebook computers. *IPSJ SIGNotes Distributed Processing System* 2002; 107: 139-144.
- ITU-R BT.500-11 Methodology for the Subjective Assessment of the Quality of Television Pictures, March 2002. ITU-R Recommendations.
- Ohashi K, Gomi Y, Mizushima H, Tanaka H. Proposal of secured medical network with TCP2. *Proc JAMI* 2004; 3G: 2-3.
- JGN (Japan Gigabit Network). Japan Gigabit Network; c2004 (updated 2004 March 1). Available from: http://www.jgn.nict.go.jp/jgn_archive/english/02-about/2-1.html/
- ITU-R BT.500-7 Methodology for the Subjective Assessment of the Quality of Television Picture, October 1999. ITU-R Recommendations.
- The picture quality assessment system (VP21S). K-Will Corporation; c2007 (updated 2007 Feb 21). Available from: <http://www.kwillcorporation.com/products/VP21S.html/>.
- Total Telecommunication Technology. T.T.T. Co., Ltd.; c1996-2007. Available from: <http://www.tttnet.ne.jp/>.
- Zhang J, Yu F, Sun J, Yang Y, Liang C. DICOM image secure communications with Internet protocols IPv6 and IPv4. *IEEE Trans Inf Technol Biomed* 2007; 11 (1): 70-80.
- APAN (Asia Pacific Area Network). Asia-Pacific Advanced Network; c2007 (updated 2007 May 5). Available from: <http://www.apan.net/>.

Appendix

Performance of Core Protocol Stacks of TCP2

We measured the performance of core protocol stacks of TCP2 in comparison with those of the ordinary TCP before mounting TCP2 on DVTS. We prepared a PC installed with TCP2 using the AES encryption algorithm (128 bit). A loop-back program was mounted on the TCP2 core protocol stacks. This test program transmitted 10,220 bytes of data, because MSS (Maximum Segment Size) of TCP is 1460 bytes and we should

use the multiplication of this segment size (we used 7 times of it). We received their replication in the core memory through the loop-back program. These procedures were repeated for 20 sec and the number of TCP/UDP payload data was counted.

According to Appendix Figure, the performance of TCPsec and UDPsec was about one-half of the conventional TCP and UDP, respectively. The bandwidth of the network that we used for telediagnostic experiments ranged from 100 Mbps to 156 Mbps so that this throughput was sufficient for transmission of images by DVTS. There would actually be no difference if we used broad bandwidth networks.

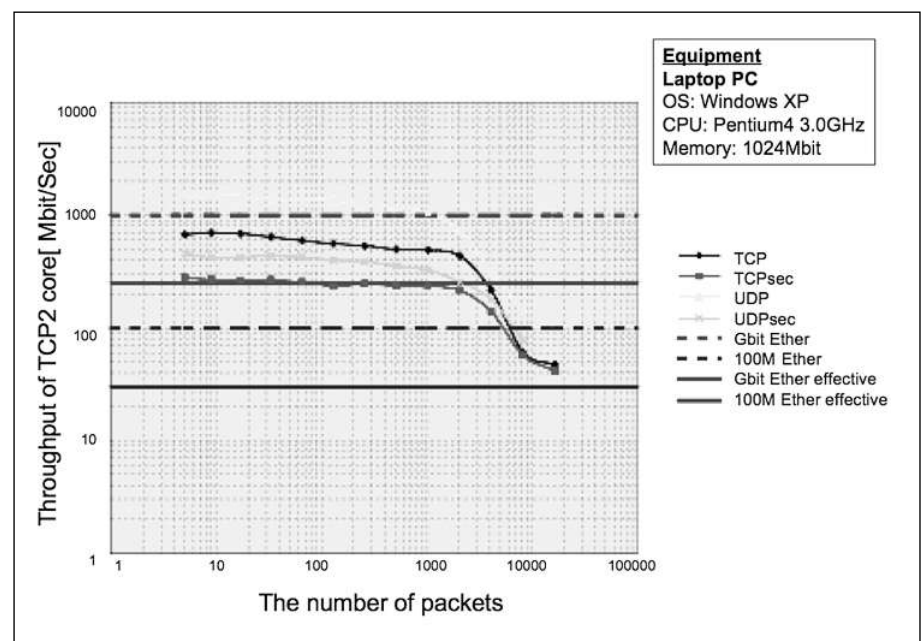


Fig. 6 The throughput performance of TCP2

11. DeBaley ME. Telemedicine has now come of age. *Telemed J* 1995; 1: 3-4.
12. Lewin M, Xu C, Jordan M, Borchers H, Ayton C, Wilbert D, et al. Accuracy of pediatric echocardiographic transmission via telemedicine. *J Telemed Telecare* 2006; 12(8): 416-421.
13. Yamazaki Y, Saida T, Takizawa M, Murase S. Inter-hospital teledermatology conference using a video-phone network. *Igaku Butsuri* 2003; 23 (1): 40-43.
14. Seidenari S, Pellacani G, Righi E, Di Nardo A. Is JPEG compression of video-microscopic images compatible with tediagnosis? Comparison between diagnostic performance and pattern recognition on uncompressed TIFF images and JPEG compressed ones. *Telemed J E Health* 2004; 10 (3): 294-303.
15. Bruno D, Delvecchio FC, Preminger GM. Digital still image recording during video endoscopy. *J Endourol* 1999; 13 (5): 353-356; discussion 356-357.
16. Kim CY, Etemad B, Glenn TF, Mackey HA, Viator GE, Wallace MB, et al. Remote clinical assessment of gastrointestinal endoscopy (tele-endoscopy): an initial experience. *Proc AMIA Symp* 2000. pp 423-427.
17. Wildi SM, Kim CY, Glenn TF, Mackey HA, Viator GE, Wallace MB, et al. Tele-endoscopy: a way to provide diagnostic quality for remote populations. *Gastrointest Endosc* 2004; 59 (1): 38-43.
18. Rabenstein T, Maiss J, Naegele-Jackson S, Liebl K, Hengstenberg T, Radespiel-Troeger M, et al. Tele-endoscopy: influence of data compression, bandwidth and simulated impairments on the usability of real-time digital video endoscopy transmissions for medical diagnoses. *Endoscopy* 2002; 34 (9): 703-710.
19. Nakashima N, Okamura K, Hahm JS, Kim YW, Mizushima H, Tatsumi H, et al. Telemedicine with digital video transport system in Asia-Pacific area. *Proceedings of Advanced Information Networking and Applications (AINA) 2005*. pp 253-257.
20. Yamaguchi M, Haneishi H, Fukuda H, Kishimoto J, Kanazawa H, Tsuchida M, et al. High-fidelity video and still-image communication based on spectral information: Natural Vision system and its applications. *Spectral Imaging: Eighth International Symposium on Multispectral Color Science. Proc. SPIE-IS&T Electronic Imaging, SPIE 2006*. p 6062.
21. Miyake Y, Miyata K. Color image processing based on spectral information and its application. *Image Processing 1999. ICIIP 99. Proceedings International Conference 1999*; 3: 41-44.
22. Linkous JD. Toward a rapidly evolving definition of telemedicine. Retrieved from <http://www.atmeda.org/news/definition.html/>. January 22, 2004.
23. The American Telemedicine Association ATA; c2005-06 (updated 2003 March 7). Available from: <http://www.atmeda.org/news/library.htm/>.
24. Wootton R. Realtime telemedicine. *J Telemed Telecare* 2006; 12 (7): 328-336.
25. Choong KM, Logeswaran R, Bisterb M. Cost-effective handling of digital medical images in the telemedicine environment. *Int J Med Inf* 2007; 76: 646-654.
26. HIMSS (Healthcare Information and Management System Society); c2007 (update 2007 August). Available from: <http://www.himss.org/>
27. Kuhn KA, Wurst SR, Bott OJ, Giuse DA. Expanding the Scope of Health Information Systems. *Methods Inf Med* 2006; 45 (Suppl 1): 43-52.

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