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Real-time Emergency Telemedicine System: Prototype Design and Functional Evaluation

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In this paper, an emergency telemedicine system was designed for the transmission of real-time multimedia for remote consultation, including radiological images, patient records, video-conferencing, full-quality video, ECG, BP, respiration, temperature, SpO_2, systolic and diastolic pressures and heart rate. The standardized, modular, software-based design architecture, without resorting to external hardware compression boards, enables the low-cost implementation of the telemedicine system, using the unified, systematic and compact integration of multimedia on general personal computers. Experimental tests on local networks analyze the technical aspects of designed systems, and inter-hospital experiments demonstrate its clinical usefulness.

Key Words: Emergency, multimedia, telemedicine, consultation, real-time, software

INTRODUCTION

The ultimate goal of medical services is to improve the quality of patient care, and save patients from death. In emergency situations, the timely, correct and specialized management is crucial, especially in increasing the patients' chances of survival, and in preventing patients from serious damage.[1-4] Particularly in Korea, emergency patients are delivered by ambulance to nearby hospitals, which are generally primary or secondary hospitals. The emergency medical personnel at those hospitals, or in the ambulance, are the first to treat the patients, but they sometimes do not have the specialized knowledge to handle serious emergency situations. Medical specialists, such as radiologists, cardiologists, neurosurgeons or orthopedist, are generally at the tertiary hospitals, but are seldom available at the primary or secondary hospitals. The immediate transfer to one of these tertiary hospitals is often required for the treatment of emergency patients by medical specialists. Nevertheless, the long distance and heavy traffic sometimes make patient transfers difficult. Therefore, efficient methods for both the transfer decision, and appropriate patient treatment, according to the remote specialist direction, are required for better patient care in an emergency situation.

Emergency telemedicine can provide an efficient means to overcome the limitation of distance and time in an emergency situation. Many emergency telemedicine systems have evolved for emergency personnel to communicate with remote specialists for consultation, treatment,

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diagnosis or transfer instructions.[1-5] Although the inclusion of multimedia components[6,7] can help describe the patient in more detail, few emergency telemedicine systems include a multimedia component in a unified, systematic way. As a result, such systems only present limited information to remote specialists. Moreover, MPEG-1 based telemedicine systems[7] cannot manage full-quality video (spatial resolution of 640 by 480) because of the resolution limitation of the MPEG-1 format. Other systems,[3,4,8] are only able to manage biological signals and/or video conferencing in real-time. Sometimes, an external hardware CODEC (Coder/Decoder) unit, such as a video conferencing CODEC, can make the integrated system bulky and expensive.

In this paper, a prototype emergency telemedicine system has been designed and implemented for emergency consultation. The distinct features of this system are the unified integration of multimedia components, including, particularly, a full-quality video for in-depth patient monitoring at a remote site, with software that is able to implement the required functionalities in real-time. Experimental tests on local networks have been used to analyze the technical aspects of implemented systems, and the system optimized, via tuning parameters, subjectively to run the RET (Real-time Emergency Telemedicine) over a wired network. Inter-hospital experiments have demonstrated the feasibility and effective used in an emergency situation.

MATERIALS AND METHODS

Design requirements

The functions of the RET system can support tele-consultations for both timely decision-making with regard to patient transfer, and accurate instructions for the treatment of the emergency patient, with the help of remote medical specialists. In order to exactly describe the status of an emergency patient to a remote medical specialist, the RET system includes multimedia components: ECG (Electrocardiogram), BP (Blood Pressure), respiration, oxygen saturation (SpO_2), temperature, systolic and diastolic pressures, heart rate, radiological images, patient records, full-quality video and video conferencing.

Table 1 shows the specified design constraints for those multimedia components. A transmission priority should be assigned to each component, so as to allocate multimedia streams depending on the available bandwidth of a given network. Two different acquisition methods for radiological images have been considered: one to acquire radiological images directly from the PACS (Picture Archiving and Communications System) the other to photograph radiological images indirectly by a digital camera.[9] A digital camera can also be used to photograph medical records. The audio should be managed more carefully than the video for video conferencing, because the audio is indispensable for accurate instructions and directions in the consultation process.

Table 1. Design Constraints for RET System

Data type	Priority	Real-time	Remarks
ECG wave	High	Yes	12 bits resolution, 300 Hz sampling ratio
Respiration, BP, and SpO_2 wave	High	Yes	12 bits resolution, 200 Hz sampling ratio
SpO_2 value, systolic pressure, diastolic pressure, temperature, heart rate	High	Yes	Update once per 30 seconds
Radiological images (X-ray, CT, MR etc.)	Low	No	Capture by either DICOM 3.0 or digital camera interface
Medical record	Low	No	Capture by digital camera
Full-quality video	Medium	Yes	640 × 480 resolution, 30 frames/second
Audio in video conferencing	High	Yes	Do not disturb conversation
Video in video conferencing	Low	Yes	320 × 240 resolution

Hardware architecture

A Pentium-IV processor, with 256 Mbytes RAM and a 1 GHz clock, was used as the terminal computers. The external units were interfaced to the terminal computer through the PC's add-on-boards and interface connectors, which are industry standard, and easily available. As shown in Fig. 1, the RET system consisted of two different terminals: the emergency and the specialist terminals.

The video conferencing camera (Samsung Co. Suwon, Kyunggi, Korea) was interfaced by a USB (Universal Serial Bus), and the microphone by a PCI (Peripheral Component Interconnect), via the sound card, to capture the video, with spatial and temporal resolutions of 320 by 240 and 30 frames/sec, respectively, with PCM (Pulse Code Modulation) coded sound. A full-quality camera (VC-10: Cannon Co. Tokyo, Japan) captured the motion video, with spatial and temporal resolutions of 640 × 480 and 30 frames/sec, respectively, through a video capture board (All-in-Wander: ATI Co. Markham, Ontario, Canada) with a PCI interface. The terminal computer, through an RS-232 serial interface, controlled the zoom factor and rotation angle of the full-quality camera, for the remote adjustment of the patient viewing position. A dedicated device was especially designed to acquire bio-signals from the patient monitor, which transmitted digitized data to the terminal computer, through the RS-232 serial interface. The bio- signals (ECG, BP, respiration and SpO_2) were sampled at 300 Hz with 12 bit resolution, which could acquire a text string once ever 30 seconds, for the bio-data (SpO_2 value, temperature, systolic and diastolic pressures and heart rate). The sampling rate was fixed by considering the highest bandwidth bio-signal; that of an ECG. The photographed radiological images and patient records were dumped to the terminal computer through a USB interface. An add-on LAN (Local Area Network) card (100 Mbps Ethernet) connected either the PACS network, or each terminal, to the WAN (Wide Area Network).

Software architecture

The RET application software performed the control, manipulation and compression /decompression required for transmitting and receiving multimedia over the network, between the emergency and specialist terminals. As shown in Fig. 2, the application software was defined by a set

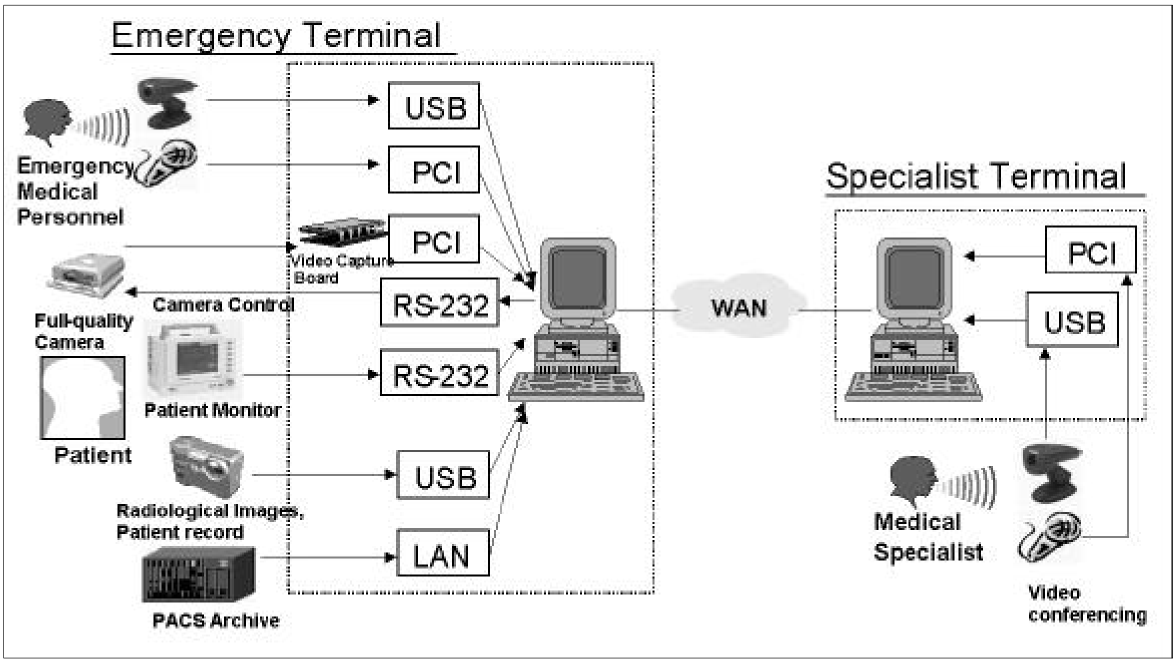

Fig. 1. Hardware configuration of the RET system.

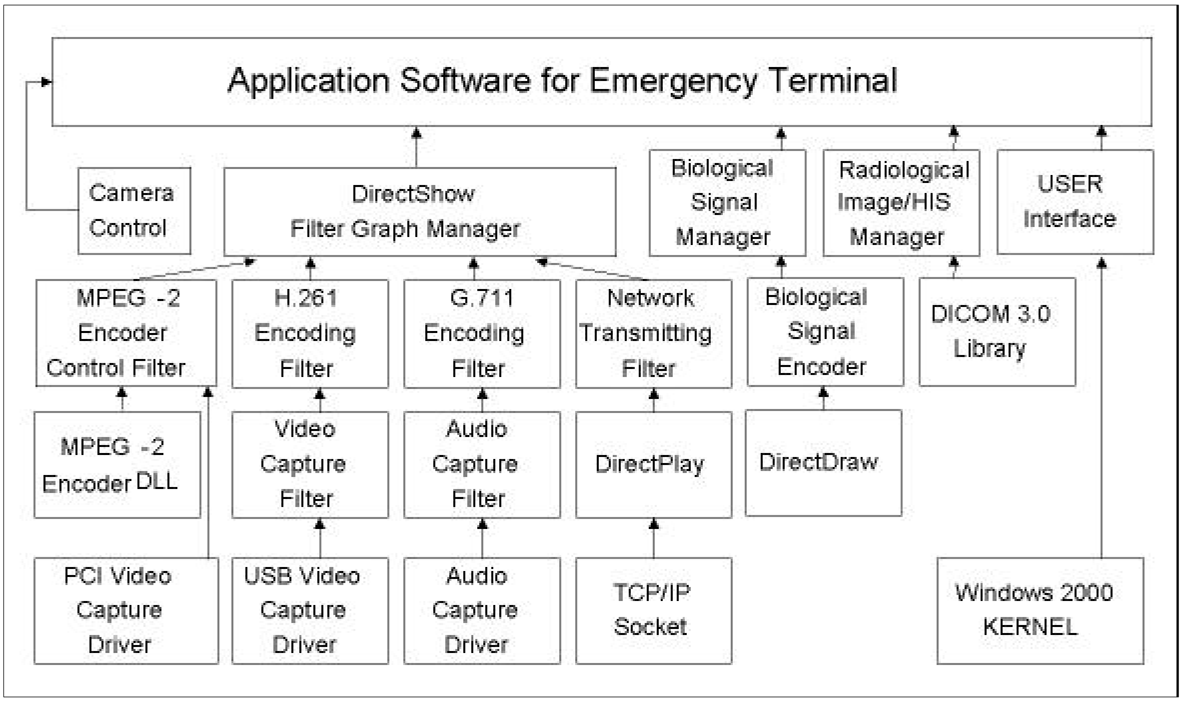

Fig. 2. Software configuration for the emergency terminal.

of objects organized in different layers, which enabled the easy and unified integration of the system with modular blocks. The lowest layer consisted of the data acquisition drivers, a TCP/IP socket for network protocol and a kernel for the user interface. The middle layer, between the lowest and highest layers (application software), consisted of the managing software, filters and dedicated blocks.

The custom-built blocks in middle layer, written in visual C++ as a COM (Component Object Model), were based on DirectShow, DirectPlay and DirectDraw (all Microsoft Co.).[12] The Direct Show filter graph manager handled most of the functions needed for the multimedia streams, including MPEG-2 encoding/decoding, H.320 encoding/decoding (video conferencing) and the transmitting/receiving of the multimedia streams over the network. DirectShow has a multimedia architecture that enables the application to have very detailed control over the media streams,[8] and used a "filter" paradigm as a component for composing filter graphs. DirectPlay, under Direct how filters, handled the transmission and reception of the multimedia streams over the TCP/IP (Transmission Control Protocol/Internet Protocol), while DirectDraw opened the application path for the management of the add-on graphics controller for a fast display. The application software collected multimedia streams and passed them to the appropriate blocks. Depending on the network capability, the quantization level is adjusted, to finalize the outgoing bit rate, and the appropriate media streams selected according to the media priority, as described in Table 1.

- The MPEG-2[10] encoder filter compresses the fine-quality video in real-time, using a MPEG-2 encoder DLL (Dynamic Link Library; Ligos Tech.).
- The custom-built H.261 and G.711 encoding filters compress the low-quality video and audio in real-time, to activate the videoconference.
- The custom-built biological signal manager collects biological signals from the patient monitor, and passes them to both the custom-built biological encoder and DirectDraw, which compress and display the biological signals, in real-time, respectively.
- The custom-built radiological image/HIS (Hos-

pital Information System) manager initiates the off-line DICOM[11] protocol, to retrieve radiological images from the PACS archive, and interpret the contents of DICOM files, to identify individual image frames, using a custom-built DICOM 3.0 library. In addition, it performs the JPEG decoding for both the DICOM compatible compressed images and the radiological image/ medical record files produced by the digital camera.

◆ The user interface consists of simple menus for choosing the functions and the tele-pointer. The tele-pointer enables the synchronous operation on the shared workspace between the emergency and specialist terminals,[13] and was designed to allow all actions initiated at different terminals to be performed in the same order and fashion at both terminals.

The important features of the custom-built blocks are their computational capability in processing the multimedia streams in real-time, their modular structures allowing the configuration of internal functions and their unified controllability for top-level applications for the effective management of the multimedia streams, depending on the individual media priority and buffer assignments requested.

Experimental setting

A two stage experiment was conducted to evaluate the technical functionality and clinical usability, by implementing prototype systems, with regard to the emergency and specialist terminals. In the first stage, a local experimental network, with a PACS connection, at the Severance hospital, was set up using a 100 Mbps fast Ethernet switching HUB (Samsung Co.) and a wireless LAN HUB (Samsung Co.), as shown in Fig. 3. In the second stage, an inter-hospital experimental network, between a medical specialist office at the Severance hospital (tertiary hospital) and an emergency room at the Seran hospital (secondary hospital), was established via two leased E1 lines (maximum bandwidth of 4 Mbps), using a CSU (Channel Service Unit) and router (CISCO 3600), with a fast Ethernet (100 Mbps) connection, as shown in Fig. 4.

RESULTS

The first stage experimentation was conducted to evaluate the technical performance of the designed prototype systems through the wire line and wireless intra network connections. With the fast Ethernet switching HUB (wire line connection), all the multimedia components can be presented to both the emergency and specialist terminals without any problems. The measured bandwidth ranged from 1.5 to 6 Mbps, depending on the amount of motion input to the MPEG-2 encoder. The frame rate and delay, for full-quality video, can reach up to 30 frames/sec, and to 2 seconds, respectively, although high motion pictures were artificially generated to test the performance of the software MPEG-2 encoder. The 2 seconds delay did not hinder the camera

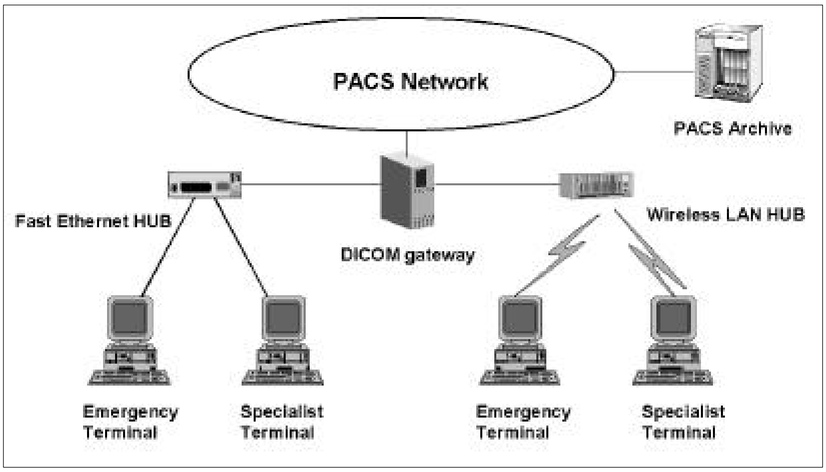

Fig. 3. Experimental network using fast an Ethernet HUB and wireless LAN HUB.

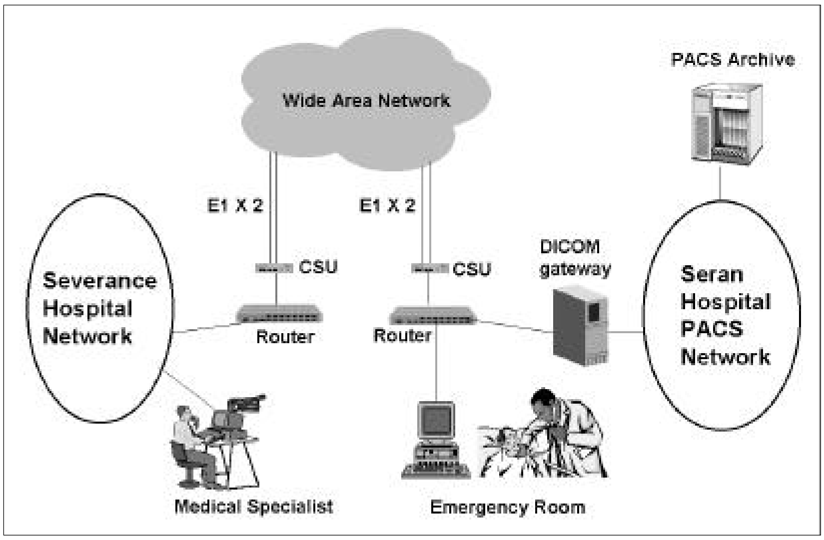

Fig. 4. Experimental setup between Severance and Seran hospital, using two leased E1 lines.

control at the remote terminal, but a too larger delay caused a problem in the remote adjustment of the camera position. The congestion of the PACS network can cause excessive delays in accessing radiological images, but this was of no concern, as a limited number of radiological images, per patient, were accessed only once from the PACS archive.

For the wireless LAN HUB (wireless connection), the measured maximum bandwidth was limited to 2.9 Mbps, which intermittently destroyed the fast motion scene after the buffer became full. However, repeated tests showed that the other received media components, with the exception of the full-quality video, did not deteriorate the real-time performance, as their streams occupied only a small portion of the bandwidth used. With high motion, the top-level application controls the priority and quantization levels, and prevents the buffer from becoming full.

In the second stage, two different hospitals were connected through the inter-hospital network. First, technical experiments between the two hospitals were conducted between 7:30 and 9:30 a.m. for two months, during times when the emergency room was not busy. For the whole testing periods, the measured bandwidth ranged from 1.5 to 3.9 Mbps, with an average throughput of about 2.5 Mbps, including all the multimedia components. As found in our previous experiments, the measured bandwidth mostly relied on the amount of motion in the MPEG-2 stream. The maximum bandwidth does not change with time, due to the guaranteed bandwidth of the leased lines, but the two E1 lines caused packets to arrive in different orders,[14] resulting in the destruction of fast motion scenes if the buffer size was not enough to compromise the different packet delays for each E1 line. Similarly to the case of wireless LAN, the other media streams, with the exception of the MPEG-2 stream, caused no problems. From this observation, a buffer size of 3.5 seconds delay was subjectively chosen, as a trade-off between the minimum destruction of fast scene motion and minimum obstruction of the camera control at the remote terminal.

Secondly, in the second stage, two clinical experiments were performed to demonstrate the clinical usefulness of the system. The first case was to simulate a case assuming a time-critical urgent situation. A manikin was used as a simulated emergency patient with breathing problems. The medical personnel at the emergency room were also assumed to have little experience of how to perform artificial respiration procedures; the traffic was also too heavy for the immediate transfer of the patient to the tertiary hospital. As shown in Fig. 5(A), the emergency personnel at the Seran hospital connected with the emergency specialist at the Severance hospital, using the patient monitor and full-quality camera. The specialist was consulted with regard to each step of the artificial respiration procedure, as shown in Figs. 5(B) to (D). While the emergency personnel

Fig. 5. Artificial respiration procedure, using a manikin, has been conducted through remote consultation. (A) System set up (B) Emergency personnel initially diagnose the patient and start to communicate with the remote specialist with regard to the patient's status. (C) Remote specialist guides on how to maintain the patient breathing (D) Emergency medical personnel conduct the artificial respiration procedure through remote consultation.

acted out each step of the artificial respiration, as directed by the specialist, the specialist was able to monitor each action of the emergency medical personnel via their terminal. The whole consultation procedure continued for about 10 minutes, with no system failure or inconvenience. The full-quality video received was acceptable to remotely guide the patient's treatment.

The second case involved an emergency patient having a severe cardiac problem, as shown in Fig. 6. After arriving at the emergency room, a chest X-ray was taken of the patient, and the 12 lead ECG examined using a chart recorder. However, the emergency medical personnel could not make the decision to either treat or transfer the patient by themselves. The consultation continued for 5 minutes through the prototype system. Sometimes, the indirect transfer of a 12 lead ECG recorded chart, through the full-quality camera (Fig. 6 (B)), could provide an auxiliary means for the remote specialist to inspect the ECG signals instead of relying on the real-time display of a 1 channel ECG on the terminal monitor. As shown in Fig. 6 (D), a tele-pointer can be used to inspect suspicious regions on the chest X-ray image at both terminals simultaneously. Throughout this consultation, the specialist finally decides if the patient should be transfer to the tertiary hospital.

DISCUSSION

In order to consult emergency medical care accurately and immediately to a remote location, the remote medical specialist should obtain sufficient information regarding the emergency patient, comprehensively and in real-time. Therefore, the emergency telemedicine system should be optimized to encompass, as far as possible, multimedia components, which sufficiently describe the emergency situation to the remote medical specialist. Moreover, both the standardization and modularity for the design of the emergency telemedicine system[13] are important factors in the

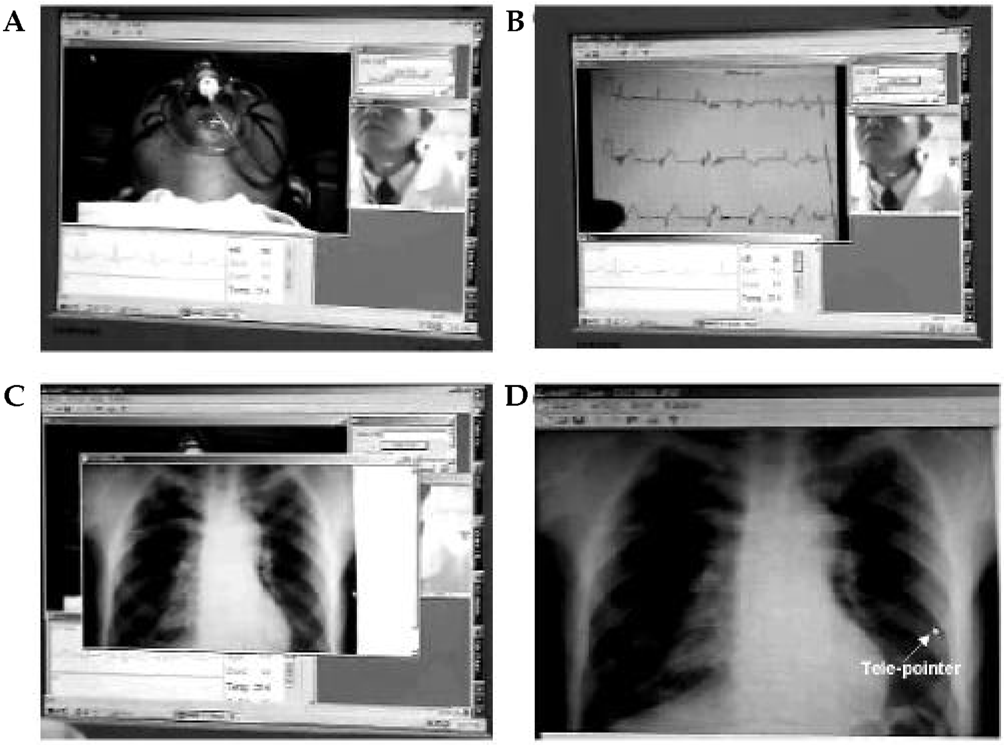

Fig. 6. The decision-making to transfer the cardiac patient to a tertiary hospital has been conducted through remote consultation. (A) Start of consultation (B) Sometimes, transmission of chart recorded ECG, using a video camera, is convenient and simple. (C) View of chest X-ray (D) Tele-pointer synchronizes the operation at both sides in inspecting the suspicious area.

compatibility of different telemedicine systems for the exchange of data, as well as for the customization, inexpensive design and future expansion. However, a few emergency telemedicine systems[1-5] have provided the unified means of integrating multimedia and transmitting changing data in real-time.

The prototype system described in this paper effectively integrated multimedia components (radiological images, medical record, biological signals, video conferencing and full-quality video) in a single computer, as well as compromising the compression, interface, medical imaging standards and modular software architectures (MPEG, JPEG, H.261, G.711, DICOM 3.0, TCP/IP, RS-232, PCI, RS-232, USB, DirectShow, DirectPlay, and COM).

Currently, the technical functions of the prototype system presented in this paper are still being continuously upgraded and tested within the testing environment prior to their clinical implementation at the emergency room for time-critical emergency patient consultation. There is a need to enhance the functionality of the prototype system. The hardware elements, including vital sign monitor and high quality video camera, should be portable and flexible for easy operation at the emergency room. The objective criteria for the patient video quality, depending on the compression ratio, frame rate, camera tilt, environmental lightening condition and the camera shaking due to movement, should be set up in terms of the network bandwidth. Moreover, the operational function should encompass more scalability to compromise diverse bandwidths of the commercially available networks, including ADSL, VDSL and leased lines. The secure transmission and storage, with authentication for the received data, should be considered to protect patient information, and to avoid medical liability problems should malpractice occur in an emergency situation. The function to acquire the medical record, through a HL (Health Level)-7 interface, should also be supplied for a direct HIS (Hospital Information System) interface.

The emergency telemedicine systems can be useful for both the timely decision of a patient transfer to another hospital and for the remote instruction of a patient's treatment in an urgent situation. In this paper, design methods for the implementation of an emergency telemedicine system, for the transmission of multimedia, in real-time, over a wired network for remote consultation are presented. In order to encompass, as far as possible, the media components required for emergency consultation, the emergency telemedicine system includes; radiological images, patient records, video-conferencing and full-quality video, as well as biological signals and data: ECG, BP, respiration, temperature, SpO_2, systolic and diastolic pressures and heart rate. The standardized, modular, software-based design architecture, without resorting to external hardware CODEC (Coder/Decoder), enables the low-cost implementation, with the unified, systematic and compact integration of multimedia on general personal computers. Experimental tests at local networks have analyzed the technical aspects of designed systems, and inter-hospital experiments demonstrated the feasibility and effective clinical use in the emergency room.

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