A Study on the Development of Remote Diagnosis System for Nerve Conduction

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Abstract

A remote measurement system for nerve conduction has been developed to aid patients with spinal cord injury by accident. Existing cooperation between rescuers and doctors can be supported through the introduction of multimedia desktop video conferencing. Such facilities provide several advantages over conventional video conferencing. In particular, patients may feel free because they can see a doctor through the video conferencing facilities. This paper describes the system implementation and evaluation. The author considers the network capability and image data handling, and introduces a method to transmit image data for this system.

I. Introduction

This work aims to use information communications technology to bring support for the diagnosis and therapy procedures through the remote system and image processing facilities. This paper is concerned with the support of the cooperation between rescuers and doctors in different locations through the introduction of a multimedia desktop conferencing system.

In contrast to many other application areas[1], video conferencing has proven successful in medical scenarios. The use of teleconferencing in medicine is often termed telemedicine. Such facilities have been used to aid in the diagnosis or planning of treatment for patients located in remote hospitals. The growing interest in telemedicine is being fuelled by the trend towards specialization in medicine, the concentration of expertise and expensive equipment in certain hospitals, and the resulting need for expert consultation.

The introduction of multimedia PCs will create opportunities for new applications in the office. Although the quality of the early systems may prove to be disappointing, video on the desktop will eventually be used to enhance existing communications systems. Electronic mail packages, for example, will be extended to incorporate new data types. Audio mail is already available. In future, users will be able to include photographs and video clips within mail messages that are sent to other users[2].

The facilities are also used for regular and spontaneous conferences between radiologists and surgeons for pre- and post operation planning (e.g. tumor conferencing). The experience has clearly shown that telemedicine can bring many benefits to patients, physicians, and hospitals. Its use can result in a faster and more precise diagnosis, an improvement in the availability of diagnostic information, it can support better communications between clinics, and can bring new opportunities to consult experts. Important for the success of these facilities is the integration in routine clinical practice.

Based on the very positive results with the conventional conferencing medium, the remote measurement system with video conferencing facilities for nerve conduction was developed on a multimedia desktop system. The aim of this system is to integrate video and audio communications in a multimedia PC environment together with applications for the access and manipulation of nerve conduction data. This leads to several important advantages over the conventional analogue conferencing facilities. There is an increasing trend, particularly in radiology and cardiology, towards the full digital acquisition and storage of medical image data.

Desktop conferencing will also improve the support of informal communications[3]. Whereas conventional conferencing systems are relatively expensive, usually located in a designated studio or lecture theater, and require the support of trained staff, desktop systems may be integrated in existing computers, can be placed in any office, and should be

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operable by all members of staff. Hence the author expects this remote system will not only support existing procedures but will also enable new opportunities for the fast and flexible cooperation between rescuers and doctors.

Using video conferencing capability this paper proposed a remote system for nerve conduction measurement. The purpose of this system is to support rescuers or patients in remote location without doctor. Video conferencing system will be helpful to make a diagnosis of patients or to give patients medical treatment as if doctor sits face to face with patients.

II. Techniques of Nerve Conduction Studies

Nerve conduction studies of motor nerve and sensory nerve are possible using electrical stimulator. NCV test results give us information about abnormality of somatosensory, nerve disease, and disease position etc. Also, if the test is repeated after constant interval the disease can be predicted.

1. Motor nerve conduction velocity

Peripheral nerves may be stimulated by passing electrical currents through the skin, resulting in a synchronized muscle contraction. When recorded by surface electrodes, this is called the compound motor action potential(CMAP). The distal latency is the interval of time between the onset of a maximal electrical stimulus to a peripheral nerve and the beginning of the CMAP in a muscle innervated by that nerve. By stimulating the peripheral nerve at two different points along its course, and by determining the interval from stimulus to response in each case, we may calculate the nerve conduction velocity(NCV).

The active recording electrode is placed over the midportion of the muscle belly (theoretically over the motor point), and the reference recording electrode is placed over the tendon of the muscle. The ground electrode is placed over an electrically inactive area, usually between the stimulating and recording electrodes. The active stimulating cathode electrode is placed over the nerve, with the cathode positioned distally. Supramaximal stimulation is used. The distance between the active recording electrode and the active stimulating electrode at the most distal site of stimulation is standardized and measured in centimeters(cm). Baseline-to-peak amplitude of the negative phase and the duration of the negative phase are measured. The amplitude, shape, and duration reflect the number and synchrony of the fibers contributing to the response. With greater asynchrony, the amplitude falls, the duration increases, and the shape becomes distorted. This is called temporal dispersion.

The NCV can be calculated[7]:

$$NCV(m/sec) = \frac{\text{Distance between two stimulation sites}}{\text{Conduction time(msec) between two stimulation sites}} \quad (1)$$

If the initial deflection of the CMAP is not negative, the following possibilities exist:

① incorrect placement of the active recording electrode on the muscle belly away from the motor point;
② transposition of the active and reference recording electrodes;
③ stimulation of other neighboring nerves by misplacement of the stimulating electrode;
④ stimulation of other nerve by stimulus spread when the stimulus exceeds supramaximal; or
⑤ conduction of the nerve impulse through anomalous innervation.

2. Sensory nerve conduction velocity

A compound nerve action potential(CNAP) produced by electrical stimulation of the afferent nerve may be recorded over peripheral sensory nerves in a number of areas.

① When stimulating the skin distally and recording over the nerve proximally, the technique is termed orthodromic.
② Under the reverse condition, the technique is called antidromic. Frequently, only one point of recording is used, and the latency obtained from stimulus to response is measured. Antidromic sensory nerve action potentials usually consist of a negative wave followed by a smaller positive wave.
③ In sensory latency techniques using the orthodromic technique, stimulating ring electrodes are placed on the digit, with the negative(cathode) electrode placed proximally.
④ Recording electrodes are placed over the nerve at a standard distance from the stimulating electrodes.
⑤ The latency from the stimulus artifact to the first negative peak of the evoked nerve action potential is recorded.

3. Compound sensory nerve action potential

A CNAP is considered to have been evoked from afferent fibers if the recording electrodes detect activity only in a sensory nerve or in a sensory branch of a mixed nerve, or if the electrical stimulus is applied to such a nerve or a dorsal nerve root, or an adequate stimulus is applied synchronously to sensory receptors. The amplitude, latency, duration, and configuration should be noted. Generally, the amplitude is measured as the maximum peak-to- peak voltage, latency to the negative peak, and the duration as the interval from the first deflection of the waveform from the baseline to its final return to the baseline. The compound sensory nerve action potential has been referred to as the sensory response or sensory potential.

III. System Design

The system presented in this paper consists of an analog signal processing unit with an analog to digital converter, an electrical stimulator, two multimedia PCs with desktop video conferencing facilities(CCD camera, video capture board, and sound card), and management software. One multimedia PC at remote place has a signal acquisition unit, electrical stimulator, and video conferencing facilities. The other multimedia PC at local hospital has nerve conduction analysis software and video conferencing facilities. The system configuration is shown Fig. 1.

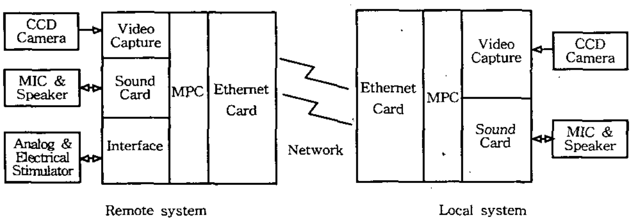


Fig. 1. Overall system configuration

1. Analog signal processing unit and electrical stimulator

The analog signal processing unit consists of an isolated preamplifier, a programmable low pass filter, and 12bit analog to digital converter.

Recorded CAP(compound action potential) signals usually in the 0.1 to 1mV range. They are amplified using a custom-made 3-stage differential preamplifier. The first stage is an instrumentation amplifier (Analog Devices AD625) with user-selectable gains of 10 and 100. The moderate gains prevent saturation due to large common mode signals. The second stage is a single pole RC filter with a cutoff frequency of 1 Hz. The high pass filter removes low frequency artifacts due to electrode polarization and motion artifacts from the cables and electrodes. The third stage is an isolation amplifier(AD210 with a gain of 101). The overall amplifier gain can be chosen at about 1,000 or 10,000.

After pre-amplification, the output signal is connected to a programmable low pass filter (AMI S3528). This is a 7th order switched capacitor elliptic filter and has dynamic range from 10 Hz to 20KHz. Filtered signal is digitized by a 12bit A/D converter and stored to local memory. After storing the nerve conduction data, the analog unit transmits EOC(end of conversion) signal to PC. When PC requests data transmission the unit sends nerve conduction data.

In General, there are two kinds of electrical nerve stimulator. One is nerve stimulator of constant voltage source with low output impedance and the other is nerve stimulator of constant current source with high output impedance. During the experiments, low output impedance affects the stimulation effect as the skin impedance varies. But nerve stimulator of constant current source is not affected by variation of skin impedance because it has high output impedance. Therefore, the system of this paper uses constant current source. Fig. 2. shows block diagram of the analog unit and electrical stimulator.

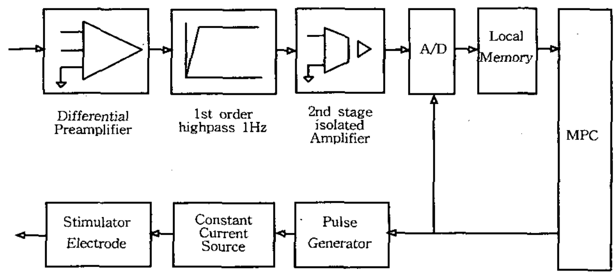


Fig. 2. Block diagram of the analog unit and electrical stimulator

2. Video conferencing facilities

In this work, two multimedia computers were used. Each computer had a video capture board(Samwoo CIMA POP 3D), CCD camera(270,000 pixels color CCD), and sound card(SoundBlaster 32IE). The goal of the conferencing system is minimization of diagnosis errors and to indicate accurate position of stimulation. Also, patients and rescuers can feel free by seeing the doctor.

Analog video is digitized so that it may be manipulated by a computer. Each frame of video becomes a two dimensional array of pixels. A complete color image is composed of three image frames, one for each color component.

Uncompressed images and video are much too large to deal with and compression is needed for storage and transmission. Important metrics of compression are the compression ratio and bits per pixel(the number of bits required to represent one pixel in the image).

Video compression is typically lossy, meaning some of the information is lost during the compression step. This is acceptable though, because encoding algorithms are designed to discard information that is not perceptible to humans or information that is redundant. There are some basic techniques common to most video compression algorithms, including color space sampling and redundancy reduction.

Color space sampling is an effective technique used to reduce the amount of data that needs to be encoded. If an image is encoded in YUV space, the U and V components can be subsampled because the human eye is less sensitive to chrominance information.

Redundancy reduction is another technique used to decrease the amount of encoded information. Intraframe encoding achieves compression by reducing the spatial redundancy within a picture. This technique works because neighboring pixels in an image are usually similar. Interframe encoding achieves compression by reducing the temporal redundancy between pictures. This technique works because neighboring frames in a sequence of images are usually similar.

In this paper, JPEG (joint photographic experts group) compression algorithm is used because the patient can't move. However, the compression algorithm for doctor's image is used QCIF (quarter common intermediate format). This is ITU-T Recommendation H.261 format. H.261 is a video compression standard designed for communication bandwidths between 64kbps and 2Mbps, measured in 64kbps intervals. This technique is also referred to as "px64" where "p" ranges from 1 to 30. H.261 was designed primarily for video conferencing over ISDN and is specified by H.320[4].

H.261 utilizes both intraframe spatial and interframe temporal encoding. In intraframe encoding mode, DCT-based spatial compression is used. In interframe encoding mode, motion compensation is performed to compute the differences between frames. The differences, usually of small magnitude, are then DCT encoded[5].

Voice data is communicated by the full duplex method and compressed using G.728[6].

3. *Software for nerve conduction analysis*

The software analysing the nerve conduction was designed under the consideration of factors affecting NCV like temperature:

Factors affecting NCV and temperature:[7]

① Distal extremities are constantly exposed to environmental temperature changes.

② There is a wide range of individual variation in response to environmental temperature changes.

③ The elderly have reduced adequate response to cold exposure. They have lower tissue temperatures than young adults when exposed to the same environment temperature.

④ Patients with impaired circulation may have reduced tissue temperature and additional reduced NCV.

⑤ Hemiplegic patients may have a lower skin temperature and motor NCV on the affected side when compared to nonaffected side.

⑥ Borderline abnormal distal latency(DL) and NCV in patients with cool extremities may lead to erroneous diagnosis, such as peripheral neuropathy, or entrapment neuropathy.

Correlation of skin temperature and NCV:

① It is practical, painless, and quick.

② Since the skin temperature varies among sites in the parts of the extremities, a specific location for temperature measurement for each nerve has to be determined in order to standardize temperature correction to NCV.

Temperature and NCV correlation factors: Temperature and NCV correlation factors vary for the same type of peripheral nerve in the literature. This variation is partially due to different tissue temperature sites, depth of thermester needle, wider range to cooling, and species variation.

NCV correlation factors are given in table 1.

Table 1. NCV correlation factors

Nerve	NCV(m/sec/1℃) skin temperature change	Skin temperature recording site
Tibial motor	1.1	15cm above medial malleolus
Sural sensory	1.7	15cm above medial malleolus
Peroneal motor	2.0	15cm above lateral malleolus
Median motor	1.5	Distal groove volar midwrist
Median sensory	1.4	Distal groove volar midwrist
Ulnar motor	2.1	Distal groove volar midwrist
Ulnar sensory	1.6	Distal groove volar midwrist
Nerve	**DL (msec)**	**Skin temperature recording site**
Median motor	-0.2	15cm above medial malleolus
Median sensory	-0.2	15cm above medial malleolus
Ulnar motor	-0.2	15cm above lateral malleolus
Ulnar sensory	-0.2	Distal groove volar midwrist

The equations considered above factors are as follows;

Tibial motor NCV corrected = 1.1 (skin temperature, 32℃) + NCV(m/sec) (2)

Sural NCV corrected = 1.7 (skin temperature, 32℃) + NCV(m/sec) (3)

Peroneal motor NCV corrected = 2.0 (skin temperature, 32℃) + NCV(m/sec) (4)

Median motor or sensory NCV or DL corrected = $CF(T_{st} - T_m)$ + obtained NCV or DL (5),

where T_{st} = 33℃ for wrist; T_m is the measured skin temperature; and CF is the correction factor of the tested nerve.

Ulnar motor or sensory NCV or DL corrected = $CF(T_{st} - T_m)$ + obtained NCV or DL (6), where T_{st} = 33℃ for wrist; T_m is the measured skin temperature; and CF is the correction factor of the tested nerve.

IV. Implementation and Evaluation

The prototype architecture of this system was illustrated in

Fig. 3. The implementation is established on Pentium-133MHz computers. the TCP/IP protocol was used for the communication over Ethernet in the laboratory. The system is designed to be able to use any computers like as notebook computer or palmtop computer.

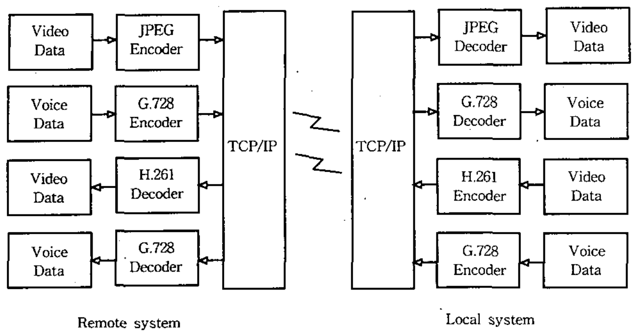


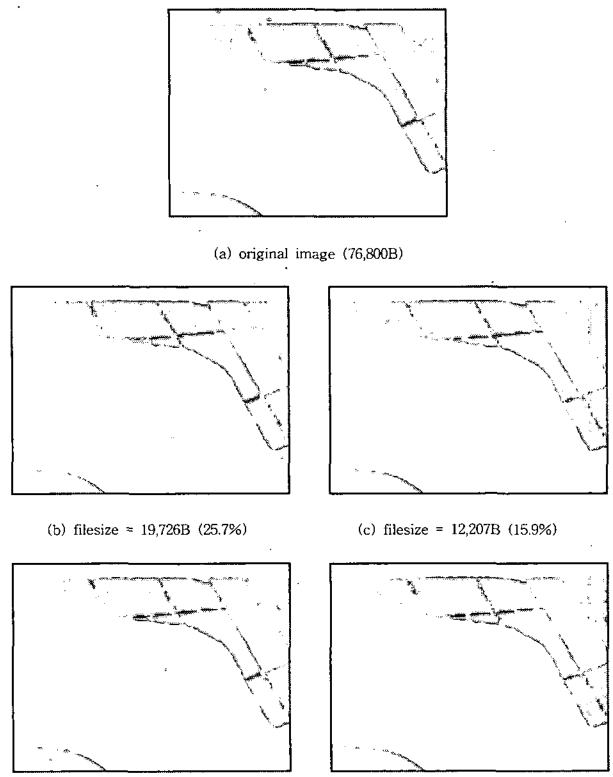
Fig. 3. System architecture

In the system implementation, one of significant problem is an image data processing. The network capability is limited by image data amount. Generally, in the case of medical image it has high resolution and large amount of data. But, this system only 320 by 240 pixels and 8bit grey level for patient's image. The image data is compressed by JPEG algorithm.

There are many types of data compression. Compression schemes like those used in zip files and GIF files are lossless compression schemes. That simply means that when you put data into the algorithm, compress it and then uncompress it later, the exact data that went into the algorithm comes out of the algorithm. This is an extremely important characteristic for things like programs which is what schemes like gzip and pkzip are typically used for. As it turns out having lossless compression of images is not very important. Initially you might balk at the idea that information is lost in compression but look at the following example.

Presented in Fig. 4 is a series of five pictures. It is the same picture used above to illustrate the size of 320 by 240 window. Fig. 4(a) is original image and compression ratio of each images((b) - (e)) are 25.7%, 15.9%, 11.3% and 8.8% respectively. The picture above is stored as a bitmap file which is a lossless compression technique. The file is 76800 bytes long. The pictures below are stored using the JPEG format which is a lossy compression technique. The JPEG compression standard allows the user to specify how lossy the compression is. The specification is called the "quality" and is expressed as a percentage. Each picture is compressed with decreasing quality. Below each picture is a caption giving the quality specification and the length of the resulting file. Notice how dramatically the file length drops as the quality specification decreases.

If we take these new numbers and look at our bandwidth bottleneck again, a compression ratio of 1:10 makes 76,800 bytes still frame only 7,680 bytes of data. Therefore, the network capability is increased by the compression ratio of the image data.



(a) original image (76,800B)

(b) filesize = 19,726B (25.7%) (c) filesize = 12,207B (15.9%)

(d) filesize = 8,643B (11.3%) (e) filesize = 6,766B (8.8%)

Fig. 4. Images of patient's leg by compression ratio

Fig. 5 is an example of measurement for sensory nerve conduction. The left upper graph is current data of nerve conduction from the remote system, left middle graph is average data of all nerve conduction data. The left lower graph is a power spectrum of average data. The right upper table is analysis results, right middle window displays patient's image data, and right lower window displays doctor's video data. In the upper table first term means latency, second term is duration, fourth term is amplitude of averaged waveform, fifth term is conduction velocity and last term is compensated conduction velocity.

The buttons at the right of patient's window means compression ratio. If the button is selected, next transmission of the image use this compression ratio. The doctor can indicate positions of EMG electrodes and stimulator electrodes by using the mouse. After click the mouse button on the electrode positions, position data are sent by selecting the trans button. The right buttons of doctor's window are on/off control buttons of microphone and speaker and control image transmission. The information of patients is sent through dialog box in order to send results or by voice communication. For the voice communication, G728 is used. G728 codes the speech at 16kbps using low-delay code excited linear prediction.

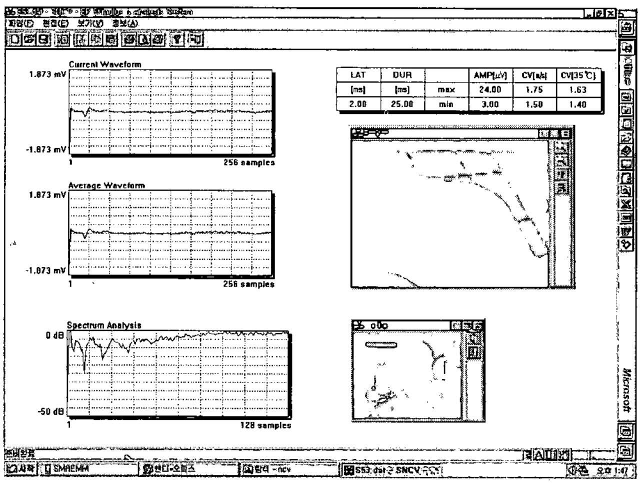


Fig. 5. Display of local system

Data length of nerve conduction received from remote system is 16,000 bytes(sampling rate is 8Ksps). Using lossless compression the data length is reduced to 8,000 bytes. Therefore, transmission time is needed about 1 second if 64kbps line is used.

The experimental results in laboratory(10Mbps Ethernet environment) show the transmission capability more than 10 frames/sec of patient image and 15 frames/sec of doctor image. If 64kbps line is used the patient image may send 1 frame/sec and doctor image may send 4-5 frames/sec. In this experiments voice communication doesn't have any problems although the quality of voice data is not good.

V. Conclusion

An initial trial of remote system to measure nerve conduction with desktop video conferencing facilities is introduced. This system is convenient to rescue patients in emergency field because it has desktop video conferencing facilities. Also, the system may be used to cure patients who want to electrical therapy in their home.

However, the future success of this system critically depends also on interoperability and the need to address the problematic of security. Also clear is that the final acceptance in routine medical practice will depend not only on such technological factors, but also on the many social and organizational aspects. This has been shown through the substantial experience with conventional conferencing. The system must be as available and quick to use as a telephone. In addition, the success in the emergency area will depend on the integration of digital archives and the adoption of open standards for image communications, rather than the common practice of proprietary solutions.

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