A Performance Evaluation and Development of 3D Endoscopic Imaging System

Chul Gyu Song, Kyeong Seop Kim, Nam Gyun Kim, and Myoung Ho Lee

Abstract - This paper represents the design of 3D endoscopic video system in order to improve visualization and enhance the ability of the surgeon to perform delicate endoscopic surgery. In comparison of the polarized and electric shutter-type stereo imaging system, The former is superior in terms of accuracy and performance speed for knot-tying and loop pass test. The result of experiments shows that the proposed 3D endoscopy system has a wide viewing angle and zone which is necessary for multi-view and it has better image quality and stability of the optical performances than the electric shutter-type does.

Key Words - 3D endoscopy, spatially multiplexed image, endoscopic data management

1. Introduction

Three-dimensional video systems have been recently developed which significantly improved visualization during minimally invasive surgical procedures. Minimally invasive techniques have set new standards in all surgical disciplines, and patients now experience less post-operative discomfort, shorter hospitalization, and quicker recuperation[1]. Although the 2-D image quality itself is quite satisfactory, the lack of depth perception may impair delicate dissection or suturing during minimally invasive procedures as one is relying on motion parallax and other indirect evidence of depth to judge the correct spatial relationship of the objects in the operating field. At times, one has to actually touch the tissues in order to gauge depth, thereby significantly reducing the speed and precision at which minimally invasive surgical procedures can be performed. This paper represents the 3D endoscopic video system design in which to improve visualization and enhance the ability of the surgeon to perform delicate endoscopic surgery[2]. This paper also covers the influence of 2D and 3D imaging on defined tasks on a laparoscopic trainer.

2. Principles of 3D Endoscopy

Human beings are capable of perceiving a three-dimensional image. The image produced on the retina of one eye differs slightly from the image produced on the other. Normally, the eyes will accommodate and converge in such way that there is intersection of the visual axes of both eyes. This intersection is know as the point of fixation

To mimic normal 3D vision, a three-dimensional video system must therefore convey separate offset images to each eye. The figure is captured in a slightly different orientation by the stereo endoscope and after image processing by the brain, it appears as a three-dimensional object(Fig.1 and Fig.2). Any 3D video system must incorporate the principles of stereopsis[3-5]. One potential limiting factor of 3D endoscopic systems is that the normal interpupillary distance for human vision is approximately 60mm, while the maximum separation of two objective lenses in a 10mm laparoscope is approximately 8 mm. However, various endoscopic designs have accounted for this disparity, still allowing for adequate capture and display of three dimensional images.

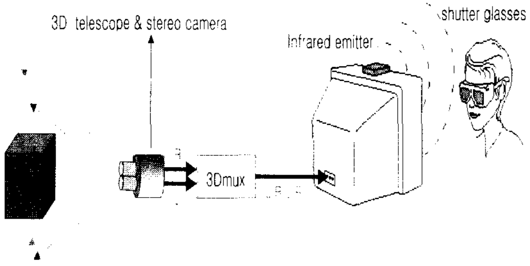

Fig. 1 Principles of the conventional 3D video system

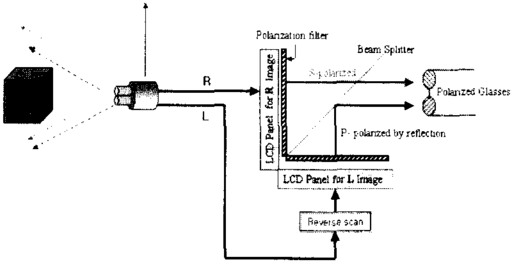

Fig. 2 The proposed 3D display system

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In this study, two 15 TFT-LCD panels for the polarization-type stereoscopic display (SM500TFT-3D) system are used so that they could display slightly different images independently captured by a two-head camera consisting of the left and right CCD (Charged Couple Device) cameras. A beam splitter was designed to transmit the S-polarized light from the upper LCD for right eye image and reflect the P-polarized light from the down LCD for left eye image to viewers as shown in Figure 2.

The P and S light from two LCDs are linearly polarized and their direction is perpendicular to each other since the direction of the polarized light from the down LCD is shifted by 90 after reflection[6-7]. Through the polarizing glasses, whose polarization directions are same as P and S, respectively, the right eye only sees the right eye image and the left eye only sees the left eye image simultaneously. Finally, it gives viewers the spatial information (i.e., depth perception).

The viewing angle versus luminescence is measured and calibrated it to luminescence differences in percentile between P-state light (the reflected image light from the down LCD) and S-state light (the transmitted image light from the upper LCD).

3. Stereoscopic Image Processing

3.1 The Proposed 3D Endoscopy System

In the present study, a newly modified electronic 3D endoscopic system is developed for the real-time processing of surgical images and surgeons comments[8-9]. Figure 3 shows a schematic organization of a complete endoscopic system. A computerized endoscopic system consists of a 3D telescope, 3D endoscope, xenon light source, a data and image handling computer linked to a magneto optical disk, a color video printer, a video cassette recorder, a foot switch, a pin microphone, and a high resolution TFT-LCD 3D monitor.

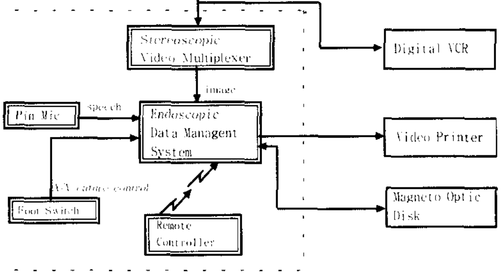

Fig. 3 Schematic organization of a complete endoscopic system allowing report generation and image handling

3.1.1 3D Telescope

The 3D telescope used in this study is the Stereo Laparoscope (Richard Wolf GmbH, Germany). The Stereo Laparoscope (10mm diameter, 25 viewing angle), attached to a camera handpiece, contains two microchip cameras. Two beam paths are guided through the double optical system. The separation of the two beam paths takes places at the proximal end of the camera device. The right beam path is presented to the right camera, and the left beam path to the left camera.

3.1.2 3D Camera

This camera is specially designed to fit 3D endoscope and therefore guarantees high picture resolution (more than 450 lines in horizontal). The endoscopic camera enables high light sensitivity (3 lux at aperture f=1.4). The 3D camera views the object from various angles, similar to that of human eyes. Two 1/2" CCD are integrated fixed focus lens f=27 mm. The video outputs of the camera system are as follows: composite video, separate Y/C, analog R/G/B signal, and digital video (8 bits).

3.1.3 Light Source

The light source has a 250 W/400 W halogen lamp and automatic brightness control dependent on the video signal. A large, continuously variable range of brightness and true color reproduction with a constant color temperature of 3200K(250W)/5600K(400W) is possible through the whole range. The video signal is only measured in a central window; this is particularly useful with small diameter images.

3.1.4 3D Video Multiplexer

In this study, 3D video multiplexer and 3D video demultiplexer are developed for 3D video recording and reproducing. The multiplexer gives field sequential stereo for recording, aligning cameras and viewing stereo with 3D monitor. The left and the right endoscopic video are recorded in a stereoscopic video signal format compatible to the NTSC protocol, a 2-fold interlace with 262.25 lines/field, and a rate of 60 fields/seconds. This format consists of alternating horizontal lines for the right and left images. The left image is stored in the even lines of pixels where as the right image is stored in the odd lines of pixels.

3.1.5 3D Video Demultiplexer

Figure 4 shows a block diagram of 3D video demultiplexer.

The decoder transforms the SVHS video into Y, U, V components and extracts timing information. The digital video tape recorder feeds a stereoplexed signal to a demultiplexer and this in turn provides independent left video and right video at twice the field frequency, with a 525 lines/field, and a rate of 60 field/seconds. Demultiplexing of the field sequential image which separates at R and L images for dual TFT-LCD 3D monitor is viewed with passive polarized glasses. The field double logic circuit is

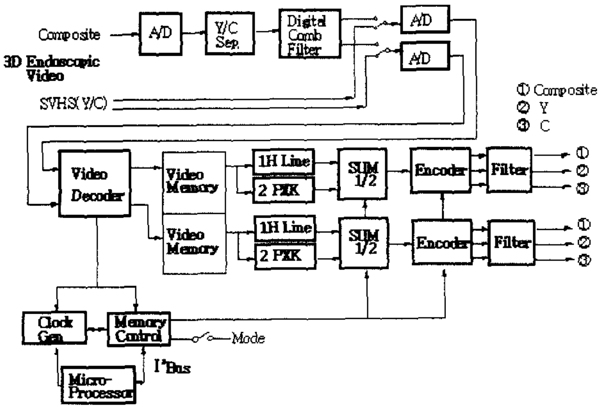

Fig. 4 Block diagram of 3D video demultiplexer

used to double the number of lines displayed to produce a smoother appearing raster. A memory controller generates a field double control signal for the first and second memories. A write address and a read address are 2-times faster than the speed of the write address.

To display a 3D image, an image conforming to the SMI (spatially multiplexed image) format is used. Viewed with polarized glasses, an SMI will appear as full-color 3D image. An SMI encodes the right and left images of a stereo pair into a single frame to form a stereo image. The SMI format consists of alternating horizontal lines (rows) for the right and left images (right, left, right, left, etc.). All of the even lines of pixels (starting from 0) contain the right image and all of the odd lines contain the left image. Multiplexed is used to form this SMI from an endoscopic stereo pair as shown in Figure 5.

Figure 6 illustrates that the viewing angle for left and right on the basis of the center of screen is in between -60 to 60. The U/D means upper and down direction of 3D monitor. The L/R means a left and right direction of monitor.

Figure 7 shows a prototype of the polarized 3D monitor with 15 TFT-LCD.

Fig. 5 Spatially multiplexed image from an endoscopic stereo pair

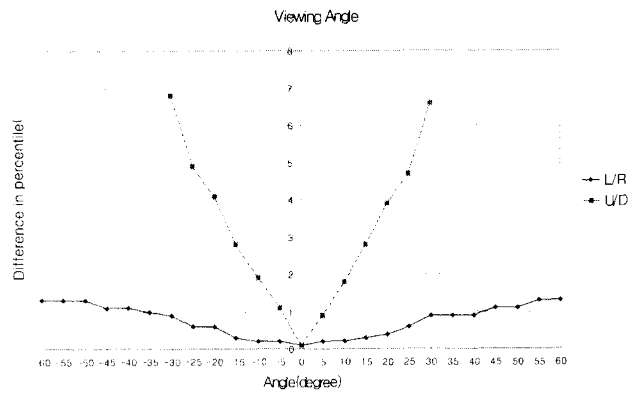

Fig. 6 Viewing angle of the proposed 3D display system

3.1.7 Endoscopic Data Management System

Figure 8 shows schematic picture of the used processing systems for the processing of endoscopic image and doctors comment in data handling.

This configuration allows the connection of all image producing devices to the endoscope, either analogic or digitized images are obtained. All these devices can be driven by the computer through its action via the handle of the endoscope. Digital endoscopic data management system is based on open architecture and a set of widely available industry standards, namely; Microsoft Windows as a operating system, TCP/IP as a network protocol and a time sequence based database that handles both images and doctor's comments. For the purpose of data storage, we used MOD and CD-R. Digital endoscopic system was designed to be able to store, recreate, change, and compress signals and medical images.

The RGB signal should be taken directly from the endoscopes CCD signal processor chip. In comparison to Y/C or composite video signal, the bandwidth for colors is increased and results in improved endoscopic image quality.

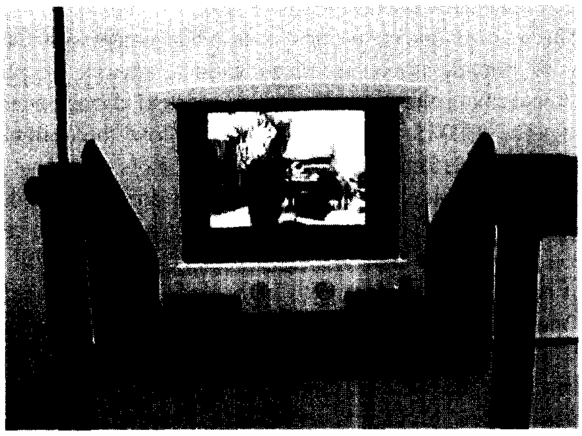

Fig. 7 Prototype of the polarized 3D monitor with 15" TFT-LCD

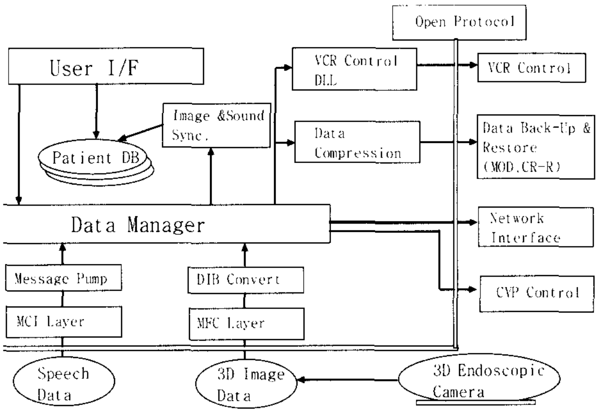

Fig. 8 Schematic diagram of the endoscopic data processing system

Our endoscopic image formats contain 640 x 480 pixels.

Digitizing the RGB signal, a variety of 16.7 million colors(24 bit)can be obtained. The endoscopic image contains around 1 Mbytes of information, a number of which is crucial for image storage. Therefore image compression algorithms have been developed, permitting a reduction in the quantity of information which has to be stored. JPEG algorithms allow a compression factor of 10 to 20 without a visible deterioration of the retrieved endoscopic images.

A system for processing digital endoscopic data is incorporated with this data manager in Fig. 8. Data manager include most of the fundamental processing library routines needed for the varied algorithms of endoscopic data manipulation. The system was developed to be run on computer systems using the Microsoft Windows system for use in surgery.

A data management scheme developed to process data in surgery. Some of the libraries used for endoscopic data managements are as follows:

1) MMDK(microsoft multimedia development kit), 2) SDK (software development kit), 3) MFC(microsoft foundation class), 4) Targa Tool Kit(True Vision Co. Ltd.), 5) VFWDK (video for windows development kit).

The goal of our endoscopic data management system(ED MS) is provide direct access to surgical images, surgeons comment about the surgical images and text documentation. Also, The EDMS designed therefore allow the following tasks to be performed: 1)image with doctors comment retrieval and display, 2) integration of the patients text database and image, 3) network interface support of high resolution display, 4) (640*480,24bit color)by the TCP/IP, 5) data back-up and restore with high capacity storage(magneto opticical Disk, CD-R).

It is never possible to completely eliminate the possibility that the data base will become corrupted. For this reason regular backup is an essential requirement. A full backup facility allows for compressed copy of the full patient data base in a MOD(3.5 inch, 640 MByte). A regular backup facility one to quickly make a regular backup at the end of each days without waiting around for a full backup once the data base has become large.

3.2 The Conventional 3D Endoscopy System

The 3D imaging system which was used is an active shutter system(3D laparoscopic system, Wolf Co. Ltd, Germany)with a 3D converter(120 Hz mode), an active shutter glasses, and a 10mm/0 binocular laparoscope. The system was used both in 2D and 3D mode.

4. Experimental Methods

Medical students (10 persons) and laparoscopic surgeons (10 persons) performed two defined tasks using 2D, the conventional electric shutter-type 3D, and the proposed polarization-type 3D endoscopic imaging. Students and surgeons repeat each task four times. The camera holder used for for two type exercises for each participant. Using laparoscopic instrument and trainer(Storz Co. Ltd.), each participant completes the following two tasks which are loop pass and suturing. For the loop pass task, a 2 cm diameter ring was hung 3 cm above the base of the laparoscopic trainer. The object(1cm x 5cm wire paper clip) was then passed from right to left through the ring. For the suturing task, Suturing was done with a 8cm long 2.0 silk suture using an RB-I curved needle.

5. Discussions

Table 1 shows the mean time(second) across experience level by mode of visualization. Each task is carried out by students and surgeons respectively (Fig. 9 and Fig. 10). The surgeons performed significantly faster in 2D and 3D than the students. Task 2(suturing) was performed an average 15 % faster by two groups(p=0.05) using 3D display. Though statistical difference between 2D and 3D were not achieved, suturing was completed 15 % faster in 3D.

The time required to perform each task was analyzed with a repeated measures analysis of variance to access the influence on performance time of group(student and surgeon) and imaging modality(2D and 3D). If there were significant group differences, Turkeys pairwise comparisons were performed to determine which two groups were significantly different at p=0.05. To analyze the effect of repeating a task three times, a repeated measure analysis was done for each imaging modality and group. The analysis of subjective survey response was done using chi-square.

With consecutive repetition, learning curves were established by analysis of task by repetition(Table 2). Students demonstrated learning with repetition in 3D for loop pass

Table 1 Mean time across experience level by mode of visualization(mean[sec]sd)

Mode Task		2D imaging	Electric shutter-type 3D	Polarizarion-type 3D
Task : 1 Loop Passing	Student	205±50	195±35	189±29
	Medical Doctor	126±37	144±28	135±26
Task 2 : Suturing	Student	690±107	532±55	512±38
	Medical Doctor	257±61	230±47	220±52

Table 2 Learning curve: anaysisi of task by repetition(a)

Mode Task		2D imaging	Polarizarion-type 3D
Task : 1 Loop Passing	Student	0.34	0.04^b
	Medical Doctor	0.06	0.75
Task 2 : Suturing	Student	0.72	0.50
	Medical Doctor	0.03^b	0.13

^{a}X = p value

^{b}(p<0.05) ; analysis of variance(ANOVA)

test. Therefore, students tended to benefit slightly more often than doctors from repetition of tasks in 3D. however, the beneficial effect could not be correlated with the difficulty of the task.

6. Results

The numeric advantages of 3D imaging will most likely translate into higher safety and better performance in the clinical use of laparoscopic procedures. The advantages are even more important in procedures with operating sites of large spatial depth. The experiment results show that the polarization-type stereoscopic display system using TFT-LCD has a wide viewing angle and zone necessary for multi-view. Also it has a better image quality and an optical performance stability than the electric shutter-type.

In comparison of the polarized and electric shutter-type stereo monitoring system, both have similar accuracy and speed for knot-tying and loop pass test. But the former is superior in image quality and performance stability. Among groups performing simple or difficult tasks, there was no significant difference in task performance between 2D and 3D, however, knot-tying were performed 15 %(p=0.05) faster in 3D by all groups.

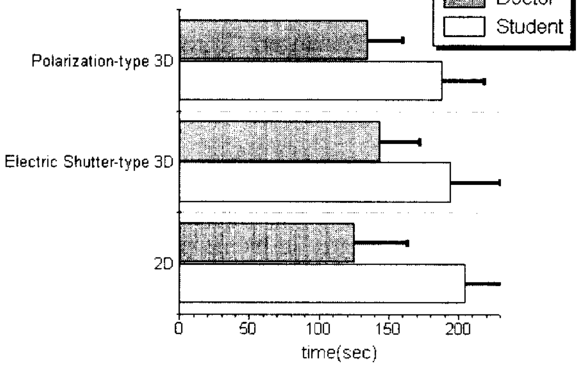

Fig. 9 Task performance of loop passing

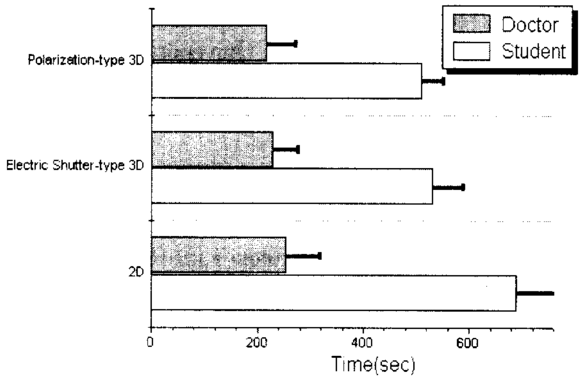

Fig. 10 Task performance of suturing

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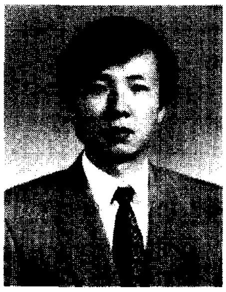

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