33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Evaluation of a Wearable Tele-Echography Robot System: FASTele in a Vehicle Using a Mobile Network

Keiichiro Ito, Koichi Tsuruta, Shigeki Sugano, *Fellow IEEE*, and Hiroyasu Iwata, *Member, IEEE*

***Abstract*—This paper shows the focused assessment with sonography for trauma (FAST) performance of a wearable tele-echography robot system we have developed that we call "FASTele". FAST is a first-step way of assessing the injury severity of patients suffering from internal bleeding who may be some time away from hospital treatment. So far, we have only verified our system's effectiveness under constantly wired network conditions. To determine its FAST performance within an emergency vehicle, we extended it to a WiMAX mobile network and performed experiments on it. Experiment results showed that paramedics could attach the system to FAST areas on a patient's body on the basis of the attaching position and procedure. We also assessed echo images to confirm that the system is able to extract the echo images required for FAST under maximum vehicle acceleration.**

I. Introduction

In current emergency medical medicine procedures, the focused assessment with sonography for trauma (FAST) method has become widespread as a first step for diagnosing traumatic shock patients [1]-[3]. FAST can narrow the diagnosis area down to four major parts, regardless of the field in which the doctor or medical staff has specialized. It is therefore a quick and easy echography method for shock patients [4], [5]. Even with this effective system, however, the time needed to transport the patient to the hospital is often excessively long. Therefore, a tele-echography system that can perform FAST in an ambulance or at an injury scene has great potential for improving the survival rate of patients.

As means of addressing this problem, many tele-echography robot systems have been developed in recent years. Salcudean et al. developed a robotic system for carotid artery tele-echography [6] that achieves a counterbalance mechanism by using a parallel link mechanism. Troccaz et al. developed a mechanism to control echo probes on the body with four cables fixed to the bed side [7]. Masuda et al. developed a mechanism that drives probes with an arm applying a pantograph mechanism, which was fixed to the bed side for the same purpose [8]. These systems, however, are in general large and need to be installed at the bed side and cannot fill portability requirements. To address this problem, Robosoft developed a portable tele-echography robotic system [9] in which a medical assistant presses an echo robot down on the patient's body and follows the instructions of a doctor in placing the probe. Its usage is limited, however, because the assistant must continuously press the robot against the patient's chest and follow the doctor's instructions on where to place the probe.

Our aim, therefore, is to develop a tele-echography system that can be used by a paramedic easily for a shock patient in an ambulance or at an injury scene. The system we developed for this purpose is a portable and attachable tele-echography robot system that we call "FASTele" [10], as shown in Fig.1. It features 4-DOF (Pitching, Rolling, Positioning, and Contacting) and is equipped with two curvature rails, a soft urethane sponge, an elastic silicon-based corset, two rotary motors, a linear motor, and two mechanical springs to generate a contact force. Not including its battery, it can be enclosed in a medium size (27×50×70 cm^3) suitcase. A paramedic attaches the FASTele to patient's body trunk directly by using the elastic silicon-based corset. We have reported its effectiveness under wired network conditions [10], but have not evaluated its FAST performance in a vehicle under a mobile network in clinical experiments. Furthermore, to our knowledge no research has been done to evaluate the performance of any wearable echography systems in a vehicle in general.

To evaluate the FAST performance of FASTele, we extended the system to a mobile network and assessed echo images in performing attaching experiment and FAST experiment on it under vehicle vibration and body motion conditions.

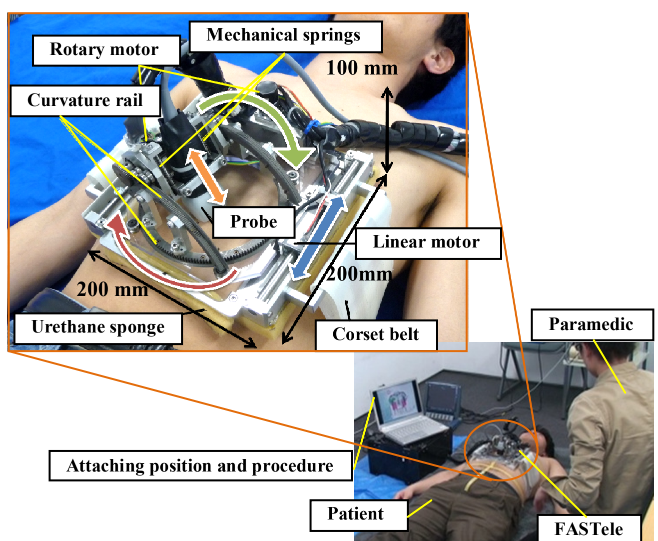


Fig.1 Portable and attachable tele-echography robot system FASTele

Keiichiro Ito, Hiroyasu Iwata, and Shigeki Sugano are with the Department of Creative Science and Engineering, School of Modern Mechanical Engineering, Waseda University, 17 Kikui-cho, Shinjuku-ku, Tokyo, 162-0044, Japan. Phone: +81-3-3203-4457, Fax: +81-3-3203-4457, E-mail :{ itokei-1985, jubi, sugano}@sugano.mech.waseda.ac.jp. Hiroyasu Iwata is also with the Waseda Institute for Advanced Study (WIAS).

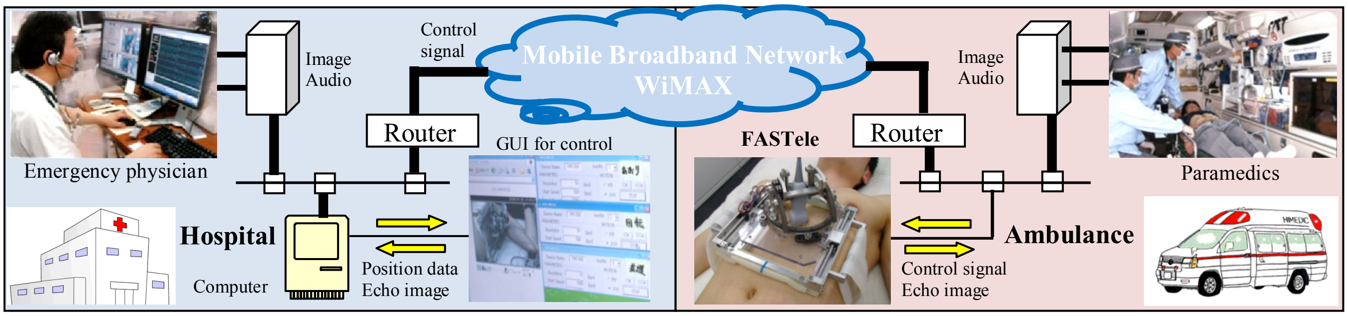


Fig.2 Overview of FASTele extended to mobile network

II. Tele-Echography Robot System: FASTele

Fig.2 shows an overview of FASTele extended to a mobile network. Different types of networks, e.g., ISDN, LAN, and WiMAX, were considered for the system. Our goal is to adapt FASTele to make it usable in ambulances and at an injury scene. We aimed to accomplish this by communicating echo images and control signals by using a mobile broadband network such as WiMAX, which can transmit data at 70 Mbps max and provide versatile communication using IEEE 802.16e.

Kawamura et al. reported a recommended network protocol for robotic tele-surgery [11]. Although the Transmission Control Protocol (TCP) maintains communication more reliably than the User Datagram Protocol (UDP) does, there is a risk in using TCP in that transmission may be discontinued to avoid overflow when the network traffic volume is increased by convergence control and retransmission of packets. Furthermore, UDP is better than TCP with respect to its ability to easily adapt to robotic tele-surgery, in which packets need to be sent in real time. Considering these factors, our decision was to use UDP for FASTele.

We implemented the PIC Network Interface Card (PICNIC) for transmitting control signals to FASTele. PICNIC also can transmit the encoder data of the FASTele under WiMAX. Implementing PICNIC resulted in a substantial improvement in the system's portability.

We used the KDDI medical image transmission system "Vista Finder" for vehicle-to-hospital echo image transmission. Vista Finder comprises a video camera, a laptop, WiMAX terminal in a vehicle and a desktop PC in a hospital. Its use of H.264 and MPEG-2 enables transmission of high-quality patient and echo images. In addition, it provides optimal performance by automatically controlling the image bit rate when the network speed changes during transmission.

The FASTele uses the SonoSite Inc. MicroMaxx product (size: 30×27×8 cm^3, weight: 3.9 kg) as a portable echo device and the company's P17/5-1 product as a sector probe. The probe frequency is 1-5 MHz and is used for the chest and abdomen. In addition, a portable AC 100-V battery was equipped in the vehicle.

Emergency physician can control the FASTele via WiMAX by using mouse interface and graphical user interface with checking the echo images and survey the situation in ambulance.

III. Experiments and Results

A. Attaching experiment with examinees

The purpose of this experiment was to verify whether the FASTele system could be attached to a patient effectively.

1) Method: A patient's body type is a key indicator for how the robot should be attached. Therefore, we used three body type classifications (slender, normal height and build, and overweight) on the basis of the BMI index (Table I) [12].

Table I Body type classifications using BMI

BMI index *1	Body Type
~ 19	Slender
20 ~ 23	Normal height and Build
24 ~	Overweight

The examinees in this experiment comprised paramedics and patients. The 9 paramedics attached the FASTele system to the patient's body, paying attention to the attaching position and procedure, as shown in Fig.3. The reference position for attaching was based on the nipple line (FAST 1, 2, 3) or the umbilici line (FAST 4). The patient's body motion due to breathing is another factor that needed to be considered. We acquired the attaching time and the attaching position data by examining the attaching position from start to finish. It was assumed that ascertaining the best attaching areas would enable a doctor to make FAST via remote control.

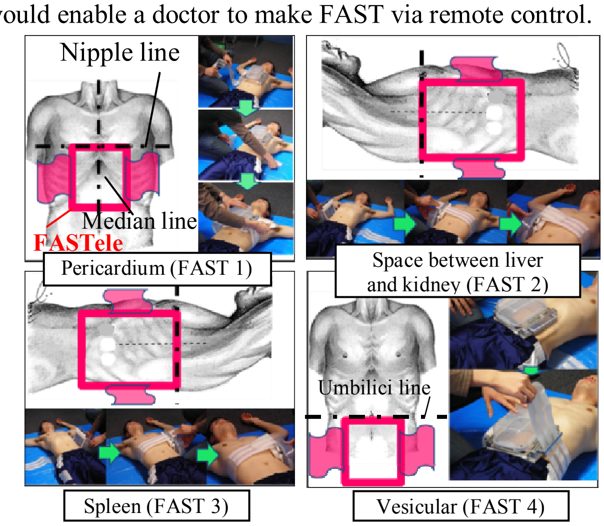


Fig.3 Attaching position and procedure

*2) **Results and Discussion***: Fig.4 shows that considerable time is needed to attach FASTele to overweight persons. This is apparently because it takes time to wrap the corset around an overweight patient's back. However, we confirmed that the mean attaching time was only about four minutes (five minutes at the most). We also confirmed that a patient's body motion due to breathing is not likely to affect the attaching time because the corset is an easily stretchable belt that paramedics can use easily. Table II shows the maximum gaps between the paramedics' attaching position and the reference line (the median line in FAST 1 and 4 and the nipple line in FAST 2 and 3). There were no cases in which it was not possible to attach the FASTele to the patient. We consider that using landmarks, such as the nipple line and the umbilici line, helps to attach the system effectively. As shown in Table II, the maximum gap was 2.7 cm in FAST 1 and 4 and 4.8 cm in FAST 2 and 3. These results confirm that the paramedics were able to attach the FASTele system to the areas required to perform FAST via doctor's remote control.

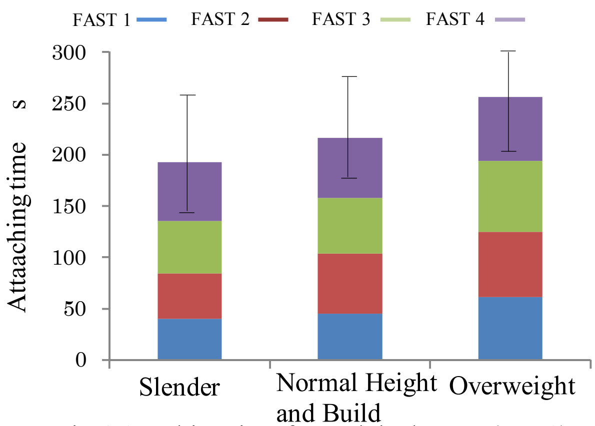


Fig.4 Attaching time for each body type (N = 9)

Table II Attaching position by examinees (maximum gap)

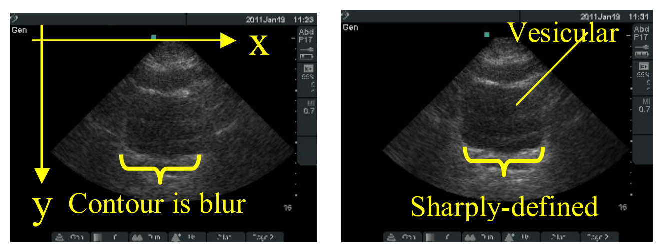
	FAST 1		FAST 4	
	Left cm	Right cm	Left cm	Right cm
Slender	1.2	1.8	1.2	2.5
Normal Height and Build	0.7	2.7	2.0	1.4
Overweight	2	0.6	2	1.5
	FAST 2		**FAST 3**	
	Head cm	Foot cm	Head cm	Foot cm
Slender	1.7	1.4	0.6	0.6
Normal Height and Build	1.4	4.3	1.9	4.8
Overweight	0	3	0	3.7

B. FAST experiment in a vehicle

The purpose of this experiment was to verify whether FASTele could be adapted to a patient's body motion and vehicle vibration.

*1) **Method:*** We used a triaxial acceleration sensor on FASTele to measure patient body motion and vehicle vibration. The echo images created under the motion and the vibration were evaluated quantitatively by focusing on echo images that medical doctors require in FAST.

The indexes used to evaluate images are resolution, contrast and sharpness. Katsuma et al. reported that the requirements for maintaining image sharpness are preserving the contours of an object, ensuring the necessary contrast, and preventing noise contamination [13]. Low-contrast images suffer from decreased sharpness as a result of decreased brightness difference and brightness gradient in the contours. This means that highly sharp images have a high contrast image because of their high brightness gradient and brightness difference. Therefore, we can evaluate echo images on the basis of contrast by focusing on the sharpness, as shown in Fig.5. In addition, the image edges, at which the average value of brightness gradient and standard variation (SD) is high, are clearly delineated. We evaluated the echo images on the basis of the average value of brightness gradient and SD.



Unclear (Low contrast) | Clear (High contrast)

Fig.5 Vesicular echo images obtained FAST 4

First, we qualitatively evaluated the images from a medical doctor's viewpoint of FAST. Next, we conducted a FAST experiment in a vehicle remotely controlled by a medical doctor and compared the images created under a patient's body motion and vehicle vibration with those obtained by the doctor on the basis of the average brightness gradient and SD values. To calculate these average values, we used image processing to extract the brightness value of each pixel. The formulas for calculating the brightness f_x (x, y) and f_y (x, y) values in the xth row and the yth column are shown by (1) and (2) below. The brightness gradient m (x, y) calculation formula is shown by (3).

$$f_x(x,y) = \frac{f(x+1,\ y) - f(x-1,y)}{2h} \tag{1}$$

$$f_y(x,y) = \frac{f(x,y+1) - f(x,y-1)}{2h} \tag{2}$$

$$m(x,y) = \sqrt{f_x(x,y)^2 + f_y(x,y)^2} \tag{3}$$

Here, h means the spacing between adjacent pixels. In this experiment, we set h as 1. The brightness gradient at each end of the image was calculated by the forward difference and backward difference, as shown by (4) and (5) below [13]. f_y (x ,y) is similar to Eqs. (4) and (5).

$$f_x(x, y) = \frac{f(x+1,\ y) - f(x, y)}{h} \quad (4)$$

$$f_x(x, y) = \frac{f(x,\ y) - f(x-1, y)}{h} \quad (5)$$

2) Results and Discussion: We confirmed that echo images could be created on the all FAST areas when the maximum acceleration of each axial direction occurred in FASTele. We also confirmed that there was no deterioration in the images. Table III shows the brightness gradient and the SD of the images extracted by the medical doctor. We confirmed that the average brightness gradient and SD values of the images that met absolutely the FAST were approximately 4.7 and 10.4 at minimum. We also confirmed that FAST cannot be performed when the average brightness gradient and SD values were lower than 3.9 and 9.8. Therefore, we defined the values as FAST criteria.

Table IV shows the brightness gradient and SD values of echo images extracted under maximum acceleration in a vehicle. We confirmed that the values were greater than the defined FAST criteria, the values required by the doctor (average brightness gradient, 3.9 and SD values, 9.8). This leads us to conclude that FASTele has FAST performance under vehicle vibration and body motion conditions.

Table III Brightness gradient and SD values of echo images extracted by a doctor

Brightness gradient	Doctor's qualitative assessment	
	Diagnosable echo images	Un-diagnosable echo images
Average Value	4.7	3.9
SD	10.4	9.8

Table IV Brightness gradient and SD values of echo images extracted under maximum vehicle acceleration

Brightness gradient	Maximum acceleration by the vehicle (m/s^2)		
	x (1.04)	y (0.82)	z (1.26)
Average mount	4.4	5.7	5.6
SD	10.5	10.1	10.0

IV. CONCLUSION AND FUTURE WORK

We extended our wearable tele-echography robot system “FASTele” to a mobile network and performed two clinical-setting experiments on it to verify its focused assessment with sonography for trauma (FAST) performance. An attaching experiment confirmed that paramedics could attach the FASTele system to each FAST area on a patient’s body on the basis of the attaching position and procedure. We also assessed echo images to confirm that there was no deterioration in the images and that FASTele could extract the highly sharp images required for FAST under in the vehicle. These results show that FASTele would performs sufficiently well in extracting the echo images required by FAST in a vehicle.

The major goal of our study is to reduce the time required to perform FAST. Presently, an attaching corset has to be wrapped around the patient's torso to fasten the robot to the patient's body. The FASTele also needs to be attached to each of the FAST areas. Currently, it seems likely that applying FASTele during FAST operation would increase the time required to perform FAST and possibly subject patients to severe injury. This is a serious problem that obviously must be addressed. In addition, the system needs to be improved to enable medical doctors to operate it easily. In future work, we will develop a new method of attaching the system to a patient so that it will not be necessary to wrap a corset around the patient's torso. We will also attempt to develop an interface that will enable the FASTele system to be controlled more easily and speedily under a mobile network in a vehicle.

ACKNOWLEDGMENT

This research was supported in part by Waseda Institute for Advanced Study (WIAS), The Ministry of Education, Culture, Sports, Science and Technology and Critical Care and Emergency Center, Yokohama City University Medical Center in Japan.

REFERENCES

[1] S. Iwai, “Japan advanced trauma evaluation and care guideline,” The Japanese association for the surgery of trauma, 2008, pp. 43–114.
[2] WS Hoff, M. Holevar and KK Nagy, “Practice management guidelines for the evaluation of blunt abdominal trauma,” The east practice management guidelines work group, 2002, 31:20.
[3] GS. Rozycki and CJ. Dente, “Surgeon-performed ultrasound in trauma and surgical critical care,” Trauma. 5th New York, 2004, pp. 311-328.
[4] BM. Decter and B. Goldner, “Vasovagal syncope as a cause of motor vehicle accidents,” AM Heart J, 1992, 1619-1621.
[5] P. Hansotia and SK. Broste, “The effect of epilepsy or diabetes mellitus on the risk of automobile accidents,” N Engl J Med, 1991, 22-26.
[6] W.H. Zhu, S.E. Salcudean, S. Bachmann and P. Abolmaesumi, “Motion/Force/Image control of a diagnostic ultrasound robot,” Proceedings of International Conference on Robotics and Automation (ICRA), 2000.
[7] A. Vilchis, J. Troccaz, P. Cinquin, K. Masuda and F. Pellissier “A new robot architecture for tele-echography,” IEEE Transactions on Robotics and Automation, vol19, No.5, 2003.
[8] K. Masuda and H. Kato, “Development of a twist pantograph mechanism for robotic tele-echography,” Proceedings of 3rd European Medical and Biological Engineering conference, No.1847, 2005.
[9] P. Arbeille, “Realtime tele-operated abdominal and fetal echography in 4 medical centres, from one expert center, using a robotic arm & ISDN or satellite link,” Proceedings of International Conference on Automation, Quality and Testing, Robotics, 2008.
[10] K. Ito, “Development of Wearable Robot for Emergency Tele-Echography”, IEEE Proc. of 32nd Annual International Conference Engineering in Medicine and Biology Society, 2010, pp.205.
[11] K. Kawamura, “Development of Real-time Simulation for Robotic Tele-surgery,” Journal of computer aided surgery, 2005.
[12] Tokunaga K, Matsuzawa Y, Kotani K, Keno Y, Kobatake T, Fujioka S, Tarui S, “Ideal body weight estimated from the body mass index with the lowest morbidity”, Int J Obes, Jan, 15(1): 1-5, 1991.
[13] H. Katsuma, T. Nishimura, “A study about characteristics of luminance gradient for the evaluation of the sharpness of an image”The institute of electronics, information and communication engineers, 2007.