2010 IEEE International Conference on Robotics and Automation
Anchorage Convention District
May 3-8, 2010, Anchorage, Alaska, USA

A Study on Wearable Behavior Navigation System - Development of Simple Parasitic Humanoid System -

Eimei Oyama, Norifumi Watanabe, Hiroaki Mikado, Hikaru Araoka, Jun Uchida, Takashi Omori, Kousuke Shinoda, Itsuki Noda, Naoji Shiroma, Arvin Agah, Kazutaka Hamada, Tomoko Yonemura, Hideyuki Ando, Daisuke Kondo and Taro Maeda

Abstract— **Performing general human behavior by experts' navigation is expected to be realized as wearable and ubiquitous technologies and computing develop. For simple, ordinary behavior, a person does not need the assistance of an expert. However, if one is standing next to an injured/ill person, one needs the instruction on performing first aid treatment from an expert. The wearer of the wearable behavior navigation system will be able to conduct first aid treatment as an expert would. We have developed the wearable behavior navigation systems using Augmented Reality technology, mainly for the navigation of the first aid treatment and for escape from dangerous areas, such as a building on fire. The effectiveness of the wearable navigation systems has been evaluated by a number of experiments. In this paper, the basic mechanism to realize general human behavior navigation is presented, along with the concrete configuration of the prototype of the navigation systems, and the experimental evaluation.**

I. INTRODUCTION

The concept of wearable computing has been actively investigated, as the physical sizes of components such as computers, sensors, actuators, etc. are becoming smaller, and the wearable virtual reality (VR) and wearable robotics have become popular research topics, similar to the popularity of wearable computers [1][2][3][4][5]. Cellular phones with Global Positioning System (GPS) navigation functions are popular now; although, that functionality is not available inside buildings. A few personal navigation systems (or human localization systems), which utilize self-contained sensors (accelerometers, gyro sensors and magnetometers), GPS, visual markers, active Radio Frequency Identification (RFID) tags, etc. for both outdoor and indoor use, have been developed [1][6][7][8][5][9]. In the near future, a person will be able to obtain miscellaneous information whenever and wherever he/she will want with these wearable technologies in the ubiquitous society. Wearable devices are available to induce the desirable direction of human walking.

Furthermore, not only the navigation of human walking, but also the navigation of general human behavior is expected to be realized as wearable technology further develops. As for ordinary behavior, a person does not need the navigation by other persons. However, if he/she is standing next to an injured/ill person, he/she needs the instruction of first aid treatment provided by an expert of first aid treatment.

In order to realize general human behavior navigation, we propose the Wearable Behavior Navigation System (WBNS). This paper focuses on the task of the wearer of the WBNS conducting first aid treatment as the expert would.

Maeda et al. developed the "Parasitic Humanoid (PH)" system. Although the PH system does not have any actuators, it can guide the wearer of the PH system to behave in desirable ways by the galvanic vestibular stimulation (GVS), the wearable moment display, and the Augmented Reality (AR) technology using the Head Mounted Display (HMD) with cameras [10][11][12][13]. Based on the technology of the PH system, we have developed prototypes of the WBNSs, which we call 'simple PH systems'. The simple PH system utilizes AR as a key technology. The main applications of the system are the navigation of the first aid treatment and the escape from dangerous areas, such as a building on a fire. The effectiveness of the wearable navigation systems have been investigated using a number of experiments.

In this paper, the basic mechanism of the WBNS, the concrete configuration of the simple PH system, and the result of an experiment, in which a subject conducts first aid treatment using a triangular bandage, are presented.

II. WEARABLE BEHAVIOR NAVIGATION SYSTEM (WBNS)

In this section, we present the concept of WBNS and illustrate how to realize the behavior navigation.

A. Basic Mechanism of Wearable Behavior Navigation System (WBNS)

The conceptual diagram of the wearable behavior navigation system is illustrated in Fig. 1. The cooperator in Fig. 1 is the non-expert who is standing next to the injured person and wants to provide him/her with first aid. As shown in Fig. 1, sensory information sharing between the expert and the cooperator is one of the main technologies of the WBNS.

This work was supported by CREST of JST and also in part by the Global COE Program of MEXT, Japan.

E. Oyama is with National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba Central 2, 1-1-1 Umezono, Tsukuba Science City, Ibaraki, 305-8568 JAPAN eimei.oyama@aist.go.jp

K. Shinoda and I. Noda are with National Institute of Advanced Industrial Science and Technology (AIST).

N. Watanabe, H. Mikado H. Araoka, J. Uchida and T. Omori are with Tamagawa University Brain Science Institute.

N. Shiroma is with Ibaraki University.

A. Agah is with The University of Kansas.

K. Hamada, T. Yonemura, H. Ando, D. Kondo and T. Maeda are with Osaka University.

N. Watanabe, K. Shinoda and T. Yonemura are also with CREST of JST.

978-1-4244-5040-4/10/$26.00 ©2010 IEEE

In order to understand the status of the injured/ill person, the expert needs sensory information of the cooperator. The WBNS realizes the feedback of the rich sensory information, which is acquired by the cooperator and then provided to the expert.

The camera on the head mounted display (HMD) of the cooperator can obtain the visual information of the cooperator. As well as the visual information, the auditory information, acquired by the microphones on the HMD of the cooperator is highly important for the communication between the expert and the cooperator and the understanding of the status of the injured/ill person.

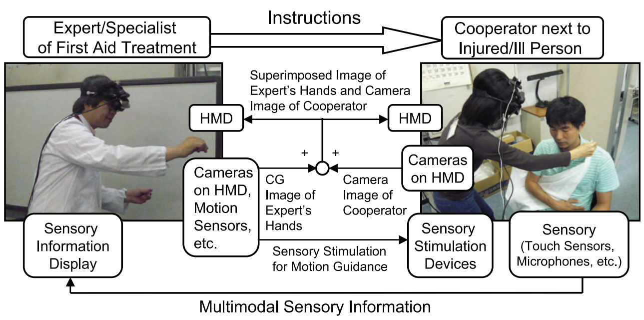


Fig. 1. Conceptual Diagram of Wearable Behavior Navigation System (WBNS)

The feedback of various senses, including the sense of touch, to the expert is desirable; although the WBNS ignores many senses since the wearable systems have limitations on their size, weight, etc. According to research on telepresence robots, which is able to display the sense of touch, the techniques for presenting the sense of touch are useful for a large number of practical teleoperation tasks [14][15]. The sensors worn by the cooperator and the sensory information display of the expert in Fig. 1 realize the sensory information feedback.

As well as the feedback of rich sensory information from the cooperator to the expert, the technique for inducing the cooperator to move as the expert moves is highly important. The most distinctive and novel technique of the WBNS is the display system, which superimposes the computer generated image of the expert over the real images captured by the cameras on the HMD of the cooperator as shown in Fig. 1. The expert and the cooperator see both the computer generated image of the expert and the real camera image of the cooperator. The cooperator can directly mimic the movements of the expert. The expert can induce the cooperator to move as the expert moves if the cooperator tries to mimic the movements of the expert.

Maeda et al. have developed PH systems [10][11][12][13]. The PH can guide the wearer of the PH to walk in a desirable course by the GVS, the wearable moment display and the AR technology using the HMD with cameras. It is possible that the sensory stimulation devices, such as the GVS and the wearable moment display, directly affect the body movements of the cooperator and induce the desirable body movements of the cooperator. However, these technologies are still under development, and it is not yet determined whether these technologies can be integrated into the practical wearable system.

B. Virtual Telerobots Societies

According to the developments of Information Technology (IT), telerobots based on the Internet have been proposed and developed for a number of years [16] [17]. Some commercial Web cameras already have had robot-like functions.

As described in science fiction works, such as “Waldo” by R. A. Heinlein, various technologies that realize and support societies in which telerobots are common, have become important research topics [16] [17]. We call such societies ’Telerobots societies.’ Minsky, who was influenced by the science fiction works, proposed the telepresence economy [18] [19]. It should be noted that telepresence is one of the key technologies of the WBNS.

R-Cubed (R3: Real-time Remote Robotics), which enables human beings to exist anywhere in the world by controlling remote robots in real time through the network, has been proposed by former Ministry of International Trade and Industry (MITI) of Japan and a number of researches have been studied them since 1995 [20][21]. The concept of ’Telerobots societies’ assumed that there would be a sufficient number of telerobots everywhere in the world. Until now, the telerobot society has not been realized because there are only a small number of telerobots in the world.

However, if a human in a remote place decides to cooperate, he/she can function as a telerobot by using the WBNS. There are possible rich resources of virtual telerobots - peoples who can agree to do this. We believe that the WBNS will contribute to realize the virtual telerobot societies of the future.

III. PROTOTYPE OF WBNS

We have developed a number of prototypes of the WBNS, and because these prototypes are based on the technologies of the PH system, we call the prototypes the simple PH system. In this section, the simple PH system is described in detail.

A. System Configuration

The simple PH system consists of two HMDs, two cameras, and the hand-made data suit with 3D motion sensors. Each HMD is equipped with one camera and one 3D motion sensor, as shown in Fig. 2. One HMD is for the expert and the other is for the cooperator.

The hardware configuration of the simple PH system is shown in Fig. 3. The HMD in Fig. 2 is eMagin z800 HMD. The camera on the HMD is Logitech WebCam Pro 9000. The 3D motion sensor is NEC/TOKIN 3D Motion sensor.

The HMD has stereo two out-ear earphones. For the purpose of tele-operation through the network, two microphones are attached to the HMD.

The Field Of View (FOV) of the HMD of the simple PH system is 40 degrees diagonal and the FOV of the camera is 75 degrees diagonal. In order to obtain a rather large

FOV, the camera image is directly displayed on the display of the HMD. Therefore, the correspondence between the displayed view and the real view is distorted. It is well known that the large distortion would deteriorate work performance. The best size of the displayed FOV of the camera will be determined by future experiments.

The outputs of the 3D motion sensors are used to move the rectangular image on the display to indicate the FOV of the expert to the cooperator.

One notebook PC directly connects the expert's HMD to the cooperator's HMD. Since the simple PH system is a proof of concept study, the system does not use the network between the expert's HMD and the cooperator's HMD. The integration of the network to the PH system will be reported in near future. The notebook PC is Sony VGN-Z71JB, with the following specifications: operating system is Windows Vista Home Premium (32 bit), CPU is Intel(R) Core(TM)2 Duo CPU P9600 (2.66 GHz), memory size is 4GB, and GPU is NVIDIA GeForece 9300M GS. The display output of the PC is connected to Matrox DualHead2Go, which distributes one display signal to two displays.

Fig. 2. One Example of Simple PH System

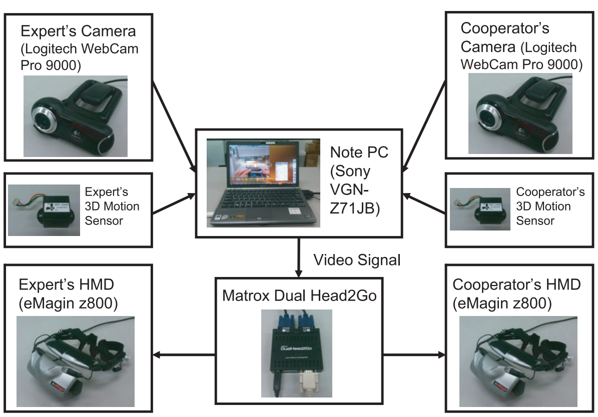


Fig. 3. Hardware Configuration of Simple PH System

Since the simple PH system has only one camera on the HMD, the system does not have the stereo display function. The extensive research on telepresence robot control has made it clear that the stereo display function is important for the sensation of presence and the performance of the operation of the telerobot. The WBNS should have at least two cameras and have the stereo display function. We have already constructed a stereo HMD for the PH system, as shown in Fig. 4. The HMD consists of a plastic frame made by using 3D printer, display system of eMagin z800 dual input, two Logitech Portable Webcam C905, and NEC/TOKIN 3D Motion sensor, and other components for attaching it to the head of the wearer. We have begun to develop new HMDs using optical see-through display system.

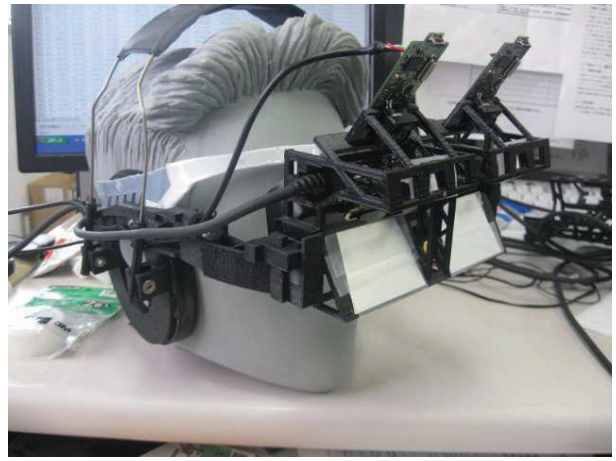


Fig. 4. Stereo HMD for Simple PH System

B. Information Processing of Simple PH

In this section, the outline of the information processing of the simple PH system is presented.

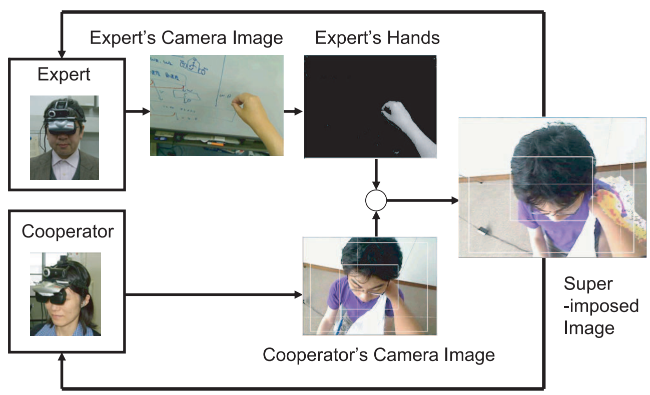


Fig. 5. Information Processing for Simple PH System

As stated in Section II, the WBNS utilize computer-generated (CG) images of the expert. However, it is still difficult to create the CG image of the expert's hands by using the wearable sensors. Therefore, the simple PH system directly uses the camera image of the expert as the CG image of the expert.

Fig. 5 illustrates the information processing of the prototype of the simple PH system. The simple PH system worn by the expert extracts the image of his/her arms from the image obtained by the camera on the HMD. The system converts the input image from RGB color space to HSV/HSL color space. Let H be the Hue of one pixel of the captured image, H_{max} be the upper bound of the hue of the image of the hands and H_{min} be the lower bound of the hue of the hands. Let S be the Saturation of one pixel of the captured image, S_{max} be the upper bound of the saturation of the image of the hands and S_{min} be the lower bound of the saturation of the hands. Let V be the Value (Lightness) of one pixel of the captured image, V_{max} be the upper bound of the value of the image of the hands and V_{min} be the lower bound of the value of the image of the hands. The system extract the image region of the hands as the region, which satisfies the following inequalities.

$$H_{min} < H < H_{max} \quad (1)$$

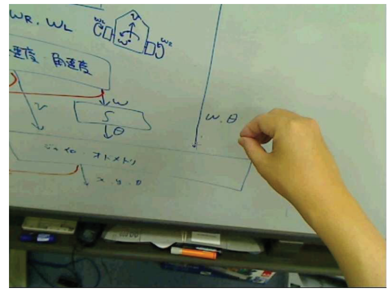
$$S_{min} < S < S_{max} \quad (2)$$

$$V_{min} < V < V_{max} \quad (3)$$

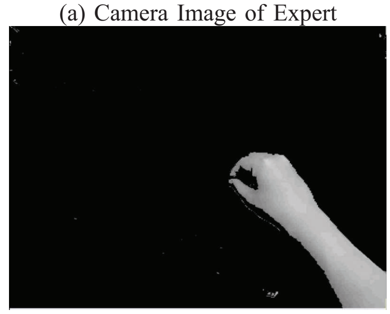
The parameters, H_{min}, H_{max}, S_{min}, S_{max}, V_{min} and V_{max} are determined manually. The image of the expert's hands, as shown in Fig. 6 (b), is the logical conjunction of the value image of the captured image and the image of the above extracted region. These image processing procedures are implemented using OpenCV [22].

The processing of the extraction of the hands image is preliminary at this stage and should be improved in the future. However, it functions as the prototype showing the effectiveness of the PH system. The extracted hands image of the expert's image and the camera image of the cooperator's HMD are overlaid as shown in Fig. 6 (d). In addition, the rectangular CG image indicating the field of view of the expert is overlaid on the image. Both the expert and the cooperator see the overlaid image on the displays of the HMDs.

Since the implementation of the image extraction of the simple PH system is primitive, the extracted image usually contains regions, which do not correspond to the image of the cooperator's body and the image extraction sometimes miss the cooperator's hands. However, in most cases, the expert and the cooperator can obtain the visual information of both the expert's hands and the cooperator's vision by high performance of the human visual understanding. In order to increase the reliability and the robustness of the hands image extraction, we are developing the extraction procedure, which utilizes the body image constructed by using the outputs of the motion sensors.

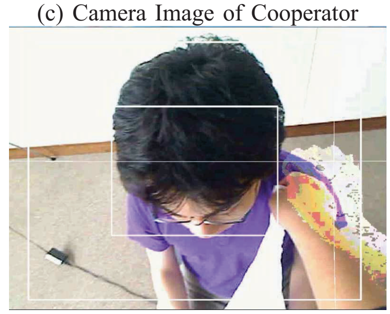


(a) Camera Image of Expert



(b) Extracted Image of Expert's Hand

(c) Camera Image of Cooperator



(d) Overlaid Image of Expert and Cooperator

Fig. 6. Image Processing of Simple PH System

Fig. 7. Arm Sling Making

IV. EXPERIMENTS

In order to evaluate the effectiveness of the simple PH systems, we have conducted basic experiments, in which we asked eight human subjects, who wear the simple PH system to make an arm sling for a person injured on his/her forearm by using a triangular bandage, as shown in Fig. 7.

A. Preliminary Experiment

Before the experiment using the simple PH system, we asked eight human subjects to make an arm sling by using a triangular bandage as a preliminary experiment. The subjects, who had no prior experience in the use of the triangular bandage, could only see the goal of the treatment as shown in Fig. 8 and were asked to make an arm sling by the triangular bandage.

The procedural steps of the preliminary experiment are as follows:

1. Explain the injured person's situation and the first aid for him/her to the subject.
2. Show the subject the goal of the first aid treatment, as shown in Fig. 8 with no explanation on how to make an arm sling.
3. Ask the subject to say "I finished." when he/she finishes the treatment.
4. Ask the subject to start to make an arm sling and ask the staff to start the timer.
5. Ask the staff to stop the timer when the subject says "I finished."
6. Check the result of the treatment

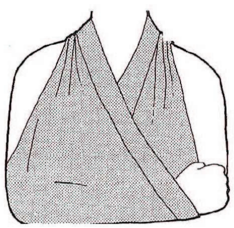


Fig. 8. Goal of Experimental Task
(Courtesy of Ibaraki MTB Network)

It was assumed that the successful treatment satisfies the following two conditions: (1) the arm sling supports the injured arm, and (2) the elbow of the injured arm is covered by the triangle bandage for stable support. Since there are several ways to make an arm sling, we check only the result of the treatment because none of the researchers involved in this experiment is a real expert.

B. Experiment with Simple PH

We asked eight human subjects, who wear the simple PH system, to make an arm sling by using a triangular bandage. Unlike the preliminary experiment, the staff whose role is being the expert, instructed the subjects on how to make an arm sling by using both visual information displayed on the HMD and audio guidance.

Fig. 9 shows the appearance of the experiment. The procedural steps of the experiment are as follows:

1. Explain the simple PH system to the subject.
2. Explain the injured person's situation and the first aid for him/her to the subject.
3. Show the subject the goal of the first aid treatment, as shown in Fig. 8.
4. Ask the subject to wear the simple PH system with the help of the research staff.
5. Ask the subject to move his/her hands as the image of the expert moves in 30 seconds.
6. Ask the subject to start to make an arm sling.
7. Check the result of the treatment.
8. Measure the time from the start of the treatment to the end.
9. Ask the subject to answer a number of questions.

Fig. 9. Appearance of Experiment

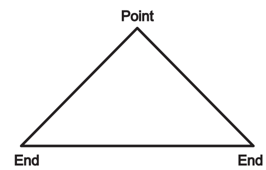


Fig. 10. Triangular Bandage

In order to describe the procedural steps of the first aid treatment, the parts of the triangular bandage include: the longest side of the triangular bandage is called the base; the corner directly opposite the middle of the base is called the point; and the other two corners are called ends, as shown in Fig. 10.

The procedural steps of the first aid treatment are as follows:

1. Hold one end of the triangular bandage by the cooperator's right arm.
2. Bring the end of the triangle bandage over the patient's left shoulder by the cooperator's right arm.
3. Move the point of the triangle bandage, which is 90 degrees beneath the injured arm by the cooperator's left arm.
4. Bring the other end of the sling over the patient's right shoulder by the cooperator's left arm, so the injured arm is cradled comfortably.
5. Tie the ends of the sling behind the patient's neck softly.
6. Check whether the arm sling supports the injured arm firmly.
7. Move the side of the patient.
8. Make a knot near the point of the bandage to fasten the bandage to support the patient's elbow.
9. Move to the back side of the patient.
10. Fasten the knot of the ends of the sling firmly.
11. Move in the front of the patient.
12. Check the arm sling.

The timer to measure the time of the treatment starts at Step 1 and stops at Step 12. The expert indicates the start and the end of the treatment to the staff in order to measure the time.

It is possible that there are issues with the above steps of first aid treatment because the researchers involved in the experiment are not real experts. However, the effectiveness of the simple PH systems can be shown by these experiments.

Fig. 11 shows the superimposed real image of the cooperator's camera and the CG image of the expert's hands, which corresponding to the above procedural steps.

Although the simple PH system includes the hand-made data suit with 3D motion sensors, and the HMD is equipped with one 3D motion sensor, the output of the 3D motion sensors were not used in these experiments since the performance of the minimum system was being evaluated in the initial stages of the development of the WBNS. The expert guides the subject to move his/hear head, and to move from one position around the patient to another, mainly by using voice.

Although the microphones and the earphones that are attached to the HMDs are available, direct voice communication between the expert and the subject are utilized in order to instruct the described steps in the experiment for simplifying the setup of the experiment.

C. Results

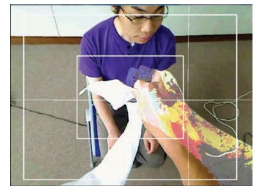
The average of the time required for the completion of the treatment, the standard deviation of the time, and the percentage of the successful treatments are shown in Table I. 'No WBNS' in Table I indicates the experimental result of the subjects without using the WBNS, and 'WBNS' indicates the experimental result of the subjects with the WBNS.

With the WBNS, all the subjects successfully completed the treatment. Without the WBNS, most subjects finished the treatment much faster than the subjects with the WBNS. However, 87.5 % of the subjects could not make an arm sling appropriately. 62.5 % of the subjects without the WBNS could not make the arm sling support the injured arm firmly. 75.0 % of the subjects without the WBNS could not cover the elbow of the injured arm by the triangle bandage.

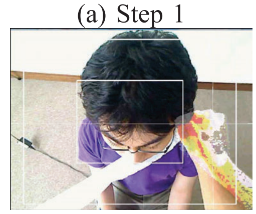
It was confirmed most average individuals do not know how to make an arm sling and they usually cannot make a complete arm sling without the help of experts. Since the eight subjects using the simple PH system successfully made an arm sling, the effectiveness of the simple PH system is proven. Although the average of the completion time was rather large, it was confirmed that the WBNS contributed to the success of the treatment.

It should be noted that a person usually make a complete arm sling in a few minutes after he/she sees a video on how to make an arm sling.

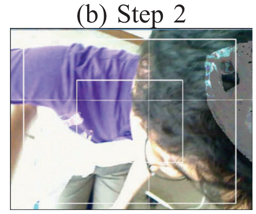
We purchased three first aid kits and one kit had illustration like Fig. 8 and the others had no illustration. It is a problem that a person probably cannot conduct an appropriate treatment even if he/her has a first aid kit.



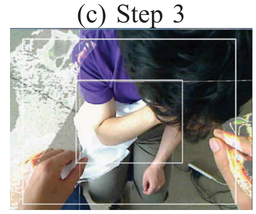
(a) Step 1



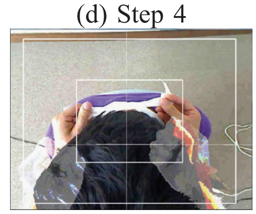
(b) Step 2



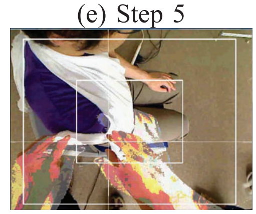
(c) Step 3



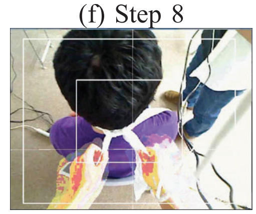
(d) Step 4



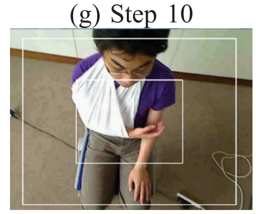
(e) Step 5



(f) Step 8



(g) Step 10



(h) Step 12

Fig. 11. Displayed Images during Experiment

According to the questionnaire that was completed after the experiments, 37.5 % of the subjects felt that the HMD was heavy. 25 % of the subjects wished for an extension of the FOV; although the extension results in more distorted correspondence between the displayed and the real views. The other 25 % of the subjects wished for the natural correspondence between the displayed and the real views; although the request results in narrow FOV. It should be noted that all the subjects have experienced neither the HMD with larger FOV, nor the HMD with the natural correspondence.

TABLE I

EXPERIMENTAL RESULTS

	Average (sec)	SD (sec)	Percentage of Success (%)
No WBNS	230.2	120.6	12.5 (1/8)
WBNS	387.2	136.3	100.0 (8/8)

D. Disscussion

A person usually makes a complete arm sling in a few minutes after he/she sees a video on how to make an arm sling. He/she finishes the treatment much faster than the subjects with the WBNS. There are three possible main reasons: (1) the deteriorated sense of distance, (2) the distorted correspondence between the displayed view and the real view, and (3) the narrow field of view of the HMD.

In order to keep the sense of distance, we already developed the advanced PH system with the stereo HMDs. The experimental evaluation of the stereo PH system will be reported in the near future. However, the natural correspondence between the displayed view and the real view and the large field of view are conflicting. The best size for the displayed FOV of the camera will be determined using future experiments.

V. CONCLUSIONS AND FUTURE WORKS

A. Conclusions

In this paper, the basic mechanism to realize the behavior navigation, the configuration of the prototype of the WBNS, and the experimental evaluation are presented. It should be noted that the simple PH system is only a prototype at this stage and it is not ready for deployment. Additional experiments and enhancements are needed before a practical version of WBNS can be realized. The intent of this paper is to illustrate the potential of the WBNS, as confirmed by the experiments reported in this paper.

B. Future Works

As stated in Section III-A, we believe that the WBNS should have the stereo display capability. Furthermore, the optical see-through HMD for the cooperator is expected to improve the performance of the cooperator. The WBNS is expected to be equipped with additional sensors and corresponding sensory information display functions, such as the sense of touch. The network function is a critical aspect of the WBNS. However, the technologies developed in numerous research efforts in telerobotics will contribute to solving the problems of the network. We will report on advanced WBNS, which integrates these functionalities, in the near future.

REFERENCES

[1] T. Starner, S. Mann, B. Rhodes, J. Levine, J. Healey, D. Kirsch, R. Picard, and A. Pentland, Augmented reality through wearable computing, *Presence*, vol. 6, no. 4, Winter, 1997, pp 386-398.

[2] M. Hirose, K. Hirota, T. Ogi, H. Yano, N. Kakehi, M. Saito, and M. Nakashige, "Hapticgear: The development of a wearable force display system", *in IEEE Virtual Reality (IEEE VR) 2001*, Yokohama, Japan, 2001, pp 123-129.

[3] Y. Seo, H. Park, H. S. Yang, "Wearable telepresence system using multi-modal communication with humanoid robot", *in 13th International Conference on Artificial Reality and Telexistence (ICAT)*, 2003.

[4] N. Sakata, T. Kurata, T. Kato, M. Kourogi, H. Kuzuoka, "WACL: Supporting Telecommunications Using Wearable Active Camera with Laser Pointer", *in 7th IEEE International Symposium on Wearable Computers ISWC2003*, NY, 2003, pp 53-56.

[5] T. Kurata, M. Kourogi, N. Sakata, U. Kawamoto, and T. Okuma, "Recent progress on augmented-reality interaction in aist", *in 2nd International Digital Image Forum: The Future Direction and Current Development of User-centered Digital Imaging Technology and Art*, 2007.

[6] T. Starner, D. Kirsch, and S. Assefa, "The locust swarm: An environmentally-powered, networkless location and messaging system", *in First International Symposium on Wearable Computers*, October 1997, pp 169-170.

[7] C. T. Judd, "A personal dead reckoning module", *in Institute of Navigation's ION 97 Conference*, Cambridge, MA, October 1997, pp 169-170.

[8] W. Rungsarityotin and T. E. Starner, "Finding location using omnidirectional video on a wearable computing platform", *in Fourth International Symposium on Wearable Computers*, Atlanta, GA, October 2000, pp 61-68.

[9] T. Okuma, M. Kourogi, N. Sakata, and T. Kurata, "3-d user interfaces for indoor exhibits navigation and reliving experiences on-and-off the spot", *in International Workshop on Ubiquitous Virtual Reality (IWUVR) 2008*, 2008.

[10] T. Maeda, H. Ando, M. Sugimoto, J. Watanabe, and T. Miki, "Wearable robotics as a behavioral interface -the study of the parasitic humanoid", in 6th International Symposium on Wearable Computers, 2002, pp 145-151.

[11] H. Ando, M. Sugimoto, and T. Maeda, Wearable moment display device for nonverbal communications, *IEICE Trans. Inf. &Syst.*, vol. E87-D, no. 6, 2004, pp 1354-1360.

[12] T. Maeda, H. Ando, and M. Sugimoto, "Virtual acceleration with galvanic vestibular stimulation in a virtual reality environment", *in IEEE VR 2005*, Bonn, Germany, 2005, pp 289-290.

[13] T. Amemiya and T. Maeda, Asymmetric oscillation distorts the perceived heaviness of handheld objects, *IEEE Transactions on Haptics*, vol. 1, no. 1, 2008, pp 9-18.

[14] M. S. Shimamoto, TeleOperator/telePresence System (TOPS) Concept Verification Model (CVM) development, *Recent Advances in Marine Science and Technology*, N.K. Saxena (ed.), Pacon International, 1992, pp 97-104.

[15] D. G. Caldwell, A. Wardle, O. Kocak and M. Goodwin, Telepresence feedback and input systems for a twin armed mobile robot, *IEEE Robotics and Automation Magazine*, vol. 3, no. 3, 1996, pp 29-38.

[16] K. Goldberg, M. Mascha, S. Gentner, N. Rothenberg, C. Sutter and J. Wiegley, "Desktop teleoperation via the world wide web", *in IEEE International Conference on Robotics and Automation (ICRA) 1995*, Nagoya, Japan, 1995, pp 654-659.

[17] K. Taylor and J. Trevelyan, "Australia's telerobot on the web", *in International Symposium on Industrial Robotics (ISIR) 1995*, 1995, pp 39-44.

[18] M. Minsky, Toward a remotely-manned energy and production economy, *A.I. Memo*, no. 544, AI Laboratory, MIT, 1979.

[19] M. Minsky, Telepresence, *Omni*, vol. 2, no. 9, 1980, pp 44-52.

[20] S. Tachi, Real-time Remote Robotics - Toward networked telexistence, *IEEE Computer Graphics and Applications*, vol. 18, no. 6, 1998, pp 6-9.

[21] S. Tachi, Telexistence and R-Cubed, *Industrial Robot*, vol. 26, no. 3, 1999, pp 188-193.

[22] G. Bradski, T. Darrell, I. Essa, J. Malik, P. Perona, S. Sclaroff, C. Tomasi, et al., OpenCV, http://opencv.willowgarage.com/wiki/, 2009.