TVRSJ Vol.25 No.3 pp.277-283, 2020

基礎論文 Paper

Development of a Telediagnosis System using Telexistence

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Abstract --- This paper proposes a telediagnosis system that allows medical staff to examine remote patients through a telexistence robot with tactile sensor/display devices. The system consists of three components, including a Six Degrees of Freedom (6 DoF) movable audio-visual telexistence system for telecommunication, body temperature and heartbeat measurement equipment, and a skin-imitated tactile display equipped with thermal/pressure presentation devices. Compared to conventional videophones, this multimodal mixed reality (MR) telediagnosis system is expected to allow medical staff to examine patients more carefully as if they are observing patients in person. Twelve experts (ten medical doctors and two nurses) evaluated the system. The results indicate that the system shows a positive feasibility for improving the realism of telediagnosis. Subsequently, the effects of telexistence with tactile information on telediagnosis are discussed.

Keywords: Telediagnosis, Telexistence, Haptics, Mixed Reality

1 Introduction

In recent years, several countries have turned into an aging society. The cost for the elderly to receive a diagnosis is always high, in terms of time spent and expenses. Hence, healthcare targeted at the aged must be improved urgently. A suitable means to achieve this objective is telemedicine. Traditional telemedicine concentrates on using information technology such as audio and video to provide medical diagnosis and other treatment from professional doctors to patients. It reduces the cost of medical treatment and cross-infection risk for infectious diseases.

However, conventional telemedicine through information technology (IT) systems such as videophones has several defects, such as its use only after initial diagnosis. The patient's condition has already stabilized, and the diagnosis process is more inclined to make a consultation rather than a medical examination. This is because only a small amount of medical information can be transmitted to the doctor. The initial diagnosis always contains several examinations to obtain essential bio-signals, which conventional telediagnosis cannot provide. Without this information, medical staff cannot determine the disease.

2 Telemedicine System

Combining virtual reality (VR) with healthcare has been proposed for decades. Early surveys reported that research using virtual reality to perform surgery and medical education dates as far back as the 1990s[1]. After that, many studies were conducted about haptic telemedicine[2, 4], online[5], and massive patient transaction[3].

With the development of VR/AR/MR, an increasing number of VR/AR/MR applications and studies in telemedicine has emerged. Telepresence surgery has already been commercialized for several years. Moreover, due to its high accuracy, surgery systems such as the da Vinci telerobotic surgical system have been increasingly used[6]. Additionally, palpation based on VR simulation has been proposed. Coles et al. use artificial force to simulate the feeling of human skin and apply the system into palpation and insertion training[7]. To achieve telemedicine, a robot with its partial function as a human is also a viable way. Garingo et al. apply a mobile robot into neonatal intensive care to help people from a distance[8].

3 System Requirements

To enable palpation between people in different places, this paper proposes a telediagnosis system with a tactile display. We hope this tactile display can be used in diagnosing difficult illnesses that cannot be determined without touch. Moreover, certain illnesses, when transferred into numerical data, seem obscure; however, symptoms can be easily understood upon being

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diagnosed by touch. The proposed system reduces the distance between the patient's home and the medical institution, eliminates the need for the aged to check in to a hospital, and enables them to receive a diagnosis at home.

The basic skills of medical examination include percussion, auscultation, and palpation. Pulse, blood pressure, and body temperature are usually measured as vital signs. We decided to reproduce palpation to acquire these vital signs as a minimum requirement for telediagnosis. Through palpation, medical staff can know the patient's pulse rate, sweating, swelling, tenderness, and temperature, or other conditions. Several diseases can be judged through palpation. In our system, we focus on reproducing temperature and pulse as these are vital information but more comfortable to measure and replicate. A human's pulse regularly ranges between 60–100 bpm. If the proposed system works effectively, additional bio-signals can be added to it to enhance its usability. Certain diseases may cause an increased heart rate beyond the normal range. For example, paroxysmal supraventricular tachycardia (PSVT) is the most common symptom of tachycardia. In this condition, the pulse rate can reach 140–180 bpm. In addition, the temperature and pulse are positively correlated. Usually, pulse increases by 10 bpm when the temperature rises by 0.5℃. Therefore, in response to the possibilities, we need to set the reproducing pulse range between 40-200 bpm on a surrogate arm to simulate arrhythmia. To this end, we choose a surrogate robot and use a surrogate arm to achieve the system. The system must follow these principles[9]. It must be real-time to ensure communication quality. A doctor must be able to see, hear, and touch the patient to judge the condition, and also see their body in the virtual space to ensure immersion and interaction.

4 System Design & Implementation

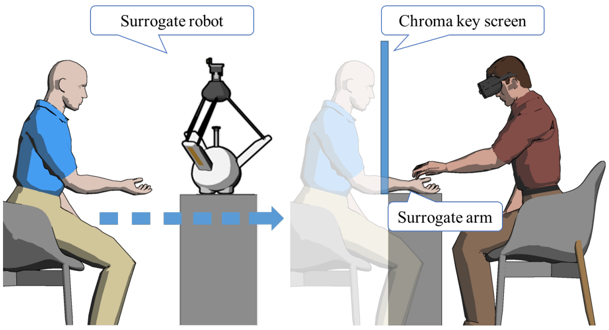

Fig.1 System schematic diagram

The system consists of two parts: the patient's side, and the doctor's side (Fig. 1, Fig. 2).

Patient's side: The patient is made to wear a glove with sensors and sit in front of a 6 DoF robot. With sensors embedded in the robot and the glove, audio-video information and bio-signals of the patient are recorded and transmitted to the doctor's side. This part comprises two components: (1) A doctor-surrogate robot perceives the surrounding information, including the patient's appearance and voice and replicates the voice and gestures recorded from the doctor's side. (2) Sensors on the glove measure the patient's pulse and temperature. The sensor data are stored and processed in a micro control unit (MCU), and subsequently, bio-signal information is transmitted to the doctor's side.

Doctor's side: The doctor wears a head-mounted display (HMD) connected to the surrogate robot on the patient's side, which reconstructs the surrounding of the patient's

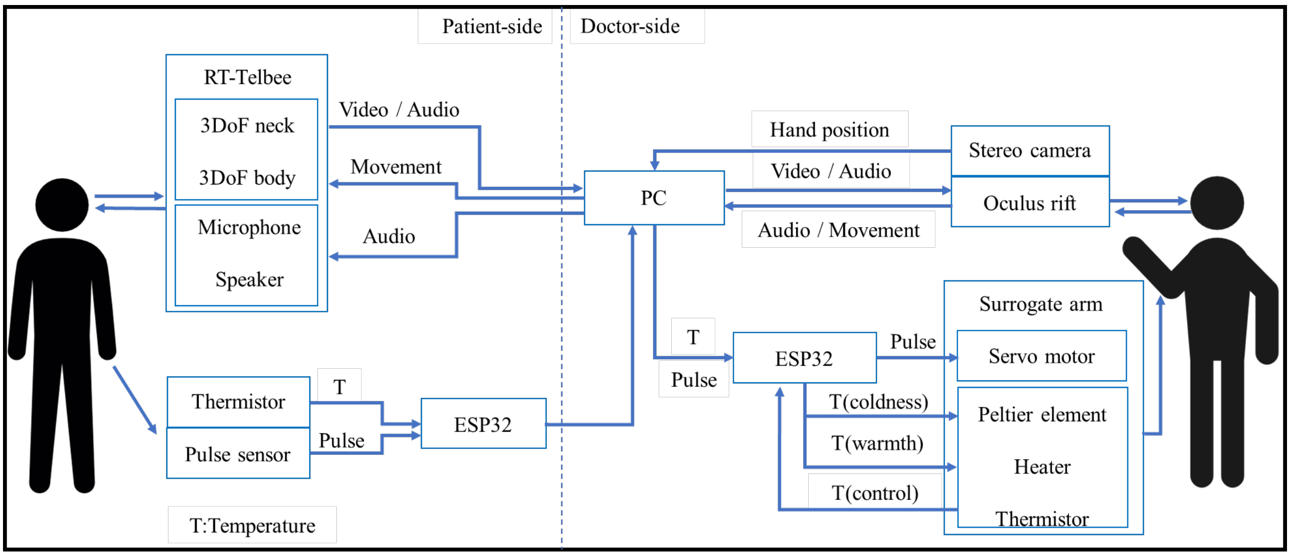

Fig.2 System data diagram

room. In addition, the HMD is equipped with a stereo camera to achieve video-seethrough capability; that is, the doctor can recognize their hands overlapping in the image of the patient's side. Except for the hands, the image on the doctor's side is eliminated using chroma key screens in a Unity project. This method realizes mixed reality. Furthermore, a patient's surrogate arm equipped with several devices is placed in front of the doctor to reproduce the patient's bio-signal information. The system is thus expected to allow the doctor to feel as if they are diagnosing the patient face-to-face

4.1 Audio-video Reproduction

4.1.1 Surrogate robot at patient'side

The robot (RT-Telbee) used on the patient's side is equipped with a stereo camera (ZED mini), binaural microphone, and speaker, enabling it to communicate like a human. Further, it has a 6 DoF mechanical system (Fig. 3), which allows the doctor's side to connect it to an HMD (Oculus Rift CV2, Facebook Technologies, LLC)[10] to control its movement. A stereo camera is affixed on the robot's head. When the robot moves, the view of the camera is also simultaneously transferred to the doctor's side.

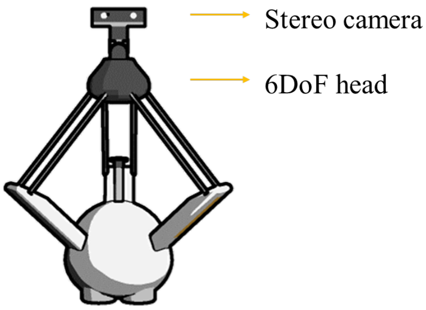

Fig.3 Construction of 6 DoF robot RT-Telbee

4.1.2 Mixed reality at doctor-side

To increase the realistic feeling and maintain the presence of the doctor's side, we attached a stereo camera on the HMD and extracted the doctor's hand from the local surroundings by using chroma key composing. The doctor can see his hand while wearing the HMD, and the hand is overlapped with the background transmitted from the patient's side, as seen in Fig. 4. As the HMD is tracking with the help of sensors and connected with the surrogate robot on the patient's side, while they move, the vision in the HMD also changes.

Fig.4 MR environment in the HMD

4.2 Bio-signal reproduction

4.2.1 Detecting glove

The patient's side uses a glove equipped with a pulse sensor (PulseSensor, World Famous Electronics llc.)[11], a negative temperature coefficient (NTC) thermistor (56A1002-C3, Alpha Sensors, Inc.), and an MCU (ESP32-WROOM-32D, Espressif Systems Pte. Ltd) to detect the pulse and temperature (Fig. 5).

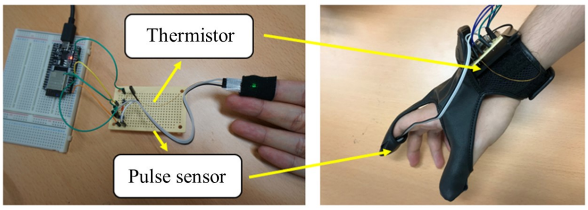

Fig.5 Bio-signal detecting glove

4.2.2 Surrogate for reproduction

The doctor's side receives bio-signal and reproduces the pulse and temperature on a surrogate arm, as depicted in Fig. 6. Under the artificial skin (a mixture of silicone and Al_2O_3 powder), a heater generates heat. A mechanical crank system applies pressure to the liquid in the tube under the wrist to imitate the pulse.

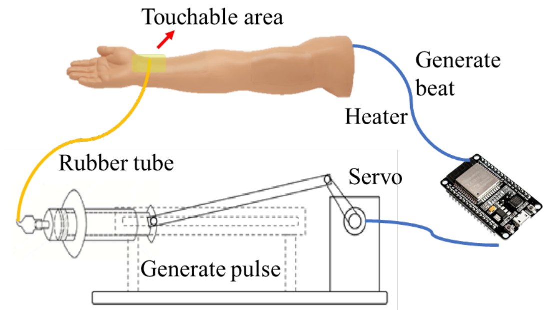

Fig.6 Mechanism of the reproduction system

However, we found that the shape of the surrogate does not matter and, therefore, developed a smaller one with a cooling module to replace the surrogate arm, as seen in Fig. 7. A heater cooperates with a Peltier element to match the temperature to that of the patient.

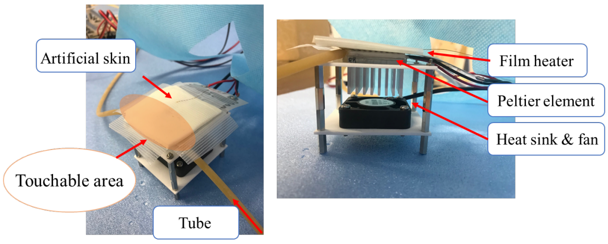

Fig.7 New surrogate with a cooling module

Fig.8 MR system in two sides (upper) and the view from the doctor/patient (below)

5 Experiments

The purpose was to test if this telediagnosis system is useful, and more specifically, to determine if it could provide a better reality as compared to the traditional telediagnosis system. Can tactile display offer more clues and benefits to the telediagnosis? We conducted an experiment with 12 medical experts (ten medical doctors and two nurses). The MR system used in the experiments is shown in Fig. 8. The participants were required to make a complete diagnosis akin to a real medical examination by using this MR system and a traditional videophone. The procedure was almost identical with the exception of the videophone method, which did not offer palpation on a tactile display.

After the experience, participants were administered two questionnaires to evaluate the system, followed by an interview.

6 Results

After using each system (VR and videophone), questionnaires included the following four statements:

Q1. I felt as if I was actually in the room with the patient.

Q2. I felt as if the patient was actually in front of me.

Q3. I felt as if the medical examination was actually performed.

Q4. I felt tense while performing the medical examination.

The results are reported in Fig. 9:

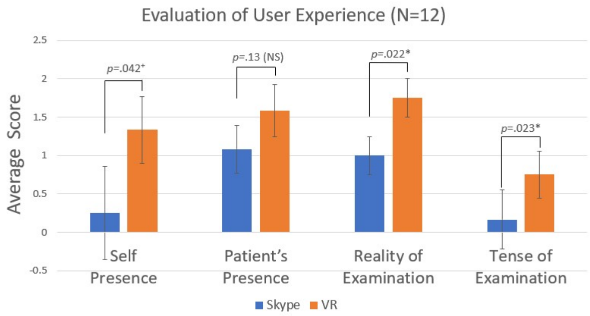

Fig.9 Evaluation of User Experience

Evaluations by 12 experts indicated that scores for the VR system are significantly better than the videophone system, with the exception of question2, i.e., “patient's presence.”

For the first question, the score of self-presence in this VR system is much better than the videophone. This indicated that telexistence was accomplished; the user's presence was successfully transferred to a remote place. This difference is a benefit from the high immersion of the telexistence system; while the participant moves his body, what they see will also change according to his movements. When the participant reaches out for palpation, they can also feel the tactile feedback. However, these features cannot be realized using the videophone alone. These factors ensure that the system has a better self-presence. During the experiment of the VR system, we noticed that doctors sometimes tried to read medical records. However, due to the poor quality of the image in the HMD, it is difficult to recognize the text. If the video quality can be upgraded, or if a virtual medical record can be added as an MR object to allow the doctor to read the text naturally and comfortably, self-presence can be further improved.

Second, regarding the patient's presence, the difference between the two average scores is not very obvious. Moreover, through the t-test, the p-value is also much higher than 0.13. From the interview after the examination, we ascertained that the main cause of this situation is the image quality in HMD. The vision in the HMD, which is cached by the stereo camera, is stereopsis like a human. It is supposed to be better than the videophone in presence. The reason several experts rated the VR system lower is probably due to the quality degradation of head tracking while performing the examination. According to experimenters' observations, when experts looked down for palpation, the angles of the experts' head occasionally tilted beyond the robot's range of motion, causing visual dislocation. While the pulse and temperature could be felt, the touched area was not the wrist in the participant's perspective. This inconsistent feeling could significantly decrease the patient's presence. Moreover, compared to question 1, although the images from both sides are cached by the stereo camera, the local side's image quality is usually better than the remote side benefited from the transmission method and has less noise. Therefore, this validates the result that the performance of self-presence is much better than the presence of the patients. Furthermore, the tactile display lends an indispensable devotion to the score of question 1.

Third, regarding the realism of examination, the experts show a positive overall judgment indicating that by using the VR system, participants could have a more realistic feel for the examination. This questionnaire item refers to their usual consultation experience. As all the subjects who participated were expert medical staff with significant diagnosis experience at hospitals, they could compare the proposed systems with their daily diagnosis, and the scores could be graded easily.

Fourth, scores of tensions show an important difference between the two methods. The tension here means the level they devoted to this telediagnosis. It reflects how seriously the experts treat the process of the diagnosis to a certain degree. Before the experiment, we intended to find something like the index of the concentration during the examination. After discussions with the medical staff, we assumed that actual medical practice creates a certain degree of mental stress for them, and the tension is directly proportional to the concentration[12]. The results revealed that the VR system brings more stress. As anticipated, this means that the experts treat it more seriously and like an actual diagnosis. However, according to the interview after the experiment, some participants said that the unfamiliar experience in VR environment will also induce some stress. Therefore, this influence should also be accounted for in this result.

After all the experiments, participants were required to share their impressions of the VR diagnosis system.

As reported in Table 1, most participants had never used similar telemedicine system (including videophones) before. However, some reported that they had on occasion performed examinations using a telephone. This suggests that even videophones were yet to become popular in clinical examinations. Furthermore, most participants agreed that the VR system presented a realistic experience akin to an actual examination. They generally indicated a positive attitude towards the VR system with the tactile display and agreed on the system's usefulness in clinical examinations. Therefore, a majority of participants answered that they wanted to try the VR telediagnosis system in real practice.

Table 1 Answer of questionnaire2

	YES	NO
Q1: Have you ever experienced another telemedicine system?	1	11
Q2.1: If Q1 is "YES," do you think the VR system is more real?	1	0
Q2.2: If Q1 is "NO," do you think the VR system is real?	10	1
Q3: Do you think VR experience is useful for the examination?	12	0
Q4: Do you think the tactile display is useful for the examination?	10	1
Q5: Do you want to use a VR telediagnosis system?	11	1

According to questionnaire results, experts rated the proposed system higher than traditional systems. However, interviews revealed that the positive evaluation is likely to include expectations of the VR telediagnosis system developed in the future. This is because problems of the current system—particularly in terms of the quality of video image—were significantly evident. Even though some respondents answered with a positive evaluation of the system in questionnaires, they also said later that the view of the VR system was poorer than videophones. Therefore, several factors emerged for their inconsistent evaluation. First, the resolution of the HMD used in the system is still insufficient to provide a clear view in comparison to the normal PC display used for videophones. Moreover, the quality of the video image captured by the stereo camera is still poor. Second, because the robot's head movement had delays and vibration, video images of the VR system were degraded. These could cause distraction and reduced immersion to the experts during the examination. However, limitations caused by hardware issues can be resolved by their improvement[13]. In addition, if they kept their heads steady, the degradation of the video image disappeared.

With many sensory clues such as immersive stereo view and touch, it is probable that they can convince the usability of the VR telediagnosis, even though the current system is still developing. In fact, we received many comments on the current system limitations. For example, skin color is often used to judge the presence of symptoms such as inflammation. Therefore, chromatic aberration of the camera image obstructs the correct judgment of the expert. One respondent claimed that chromatic clues must be presented more correctly. Actually, the determining process of disease is complicated. Therefore, to derive a correct conclusion, it is necessary to obtain many kinds of bio-signals with high accuracy. Only with enough information about the patient can the doctor confidently determine the disease. In this context, palpating the heart rate and body temperature is insufficient. According to another participant's comments, the skin's thickness, hardness and surface moisture always help with the diagnosis. Nowadays, medical staff perform palpation not only on the patient's wrist but also on the neck, foot, and other body parts, which are more effective in judging local lesions. Therefore, this system should have wilder applicability. Since the surrogate's shape is irrelevant, it can be improved to adapt more reproduction of bio-signals.

Finally, the participants were dissatisfied with comfort levels when wearing the HMD. This aspect must be considered in real practice. Many participants have shown VR sickness after using this VR telediagnosis system. Moreover, the helmet is too heavy to be worn for a long time. Medical staff will tire easily, and therefore, it is impractical in daily telediagnosis. Thus, it is necessary to improve their VR experience when diagnosing. The weight of the helmet can only be solved when the hardware undergoes improvements. However, the software can be better developed. Due to limitations of a surrogate robot, such as visual dislocation, the doctor can only move in a small range. Using a robot with more DoF may be more effective. In diagnosis, reading and writing medical records is necessary. Adding a function of the medical record will greatly improve the system. In order to have efficient communication with the patients, it is proposed that the patient side's surrogate robot arm is better equipped to simulate the doctor pressing the patient's skin, helping the patient more effectively realize the doctor's instructions.

7 Conclusion

Aiming at the current situation of telemedicine, this paper proposes a telediagnosis system to allow medical staff to palpate a remote patient in a MR environment, allowing the doctor to obtain a better observation and more necessary essential information to determine diseases. The system is based on telexistence and tactile display with a 6 DoF surrogate robot and a new surrogate unit. On the patient's side, a 6 DoF robot and sensors are used to measure body temperature and pulse rate, which are then reproduced on the doctor's side using MR and tactile display devices. Through experiments and comparisons with the traditional telediagnosis method, it was concluded that this MR system had better performance, and the effects of telexistence and tactile display on telediagnosis reflect a positive attitude. The feasibility of the system for improving the realism of telediagnosis is therefore verified

Acknowledgements

This work was supported by JST ACCEL Grant Number JPMJAC1404, Japan. We would like to thank Prof. Hiroyuki Shinoda for his support of the project. We would also like to thank Prof. Katsuya Iijima, Prof. Hiroshi Oyama, Prof. Masahiro Akishita, and Assoc. Prof. Sumito Ogawa and MD. Ayaka Fujii for their advices from doctor's point of view.

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(Received: March 31, 2020)

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