Immersive Telerobotics using the Oculus Rift and the 5DT Ultra Data Glove

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***Abstract*—there is significant interest in tele-operating simulated or physical robots in hostile environments, particularly for military, policing, medical, and gaming environments. This paper describes a developed Virtual Reality (VR) application that allows a user to control a simulated immersive robot in a combat scenario. We have incorporated a 5DT Ultra Data Glove and an Oculus Rift in our proposed combat scenario and compared our results in both an immersive and non-immersive environment. The immersive environment involves the 5DT data-glove and Oculus Rift for navigation and control. On the other hand, the non-immersive environment involves using a keyboard, mouse, and monitor. We perform a user study for both environments to assess user control interface preferences over the simulated application. Preliminary results of our post analysis survey suggest that users prefer the immersive mode of operation.**

Keywords-immersive; non-immersive; teleoperation; robotics; telepresence; virtual reality; simulation; networking; data glove; Oculus; 5DT

I. INTRODUCTION

Robots are being designed to operate autonomously or remote controlled manually by a user at a computer command console [1]. Significant developments have occurred with head mounted displays (HMD) technology, allowing for the detection of head pan, tilt, and roll orientation, as well as providing stereoscopic visual immersion. Haptic data glove technologies are also maturing and are frequently used as input to computing systems to interpret human hand gestures and to give command input to computing systems. Because there is so much interest, this paper explores immersive robotic teleoperations in a simulated hostile environment. It discusses the software application developed to allow users to control the simulated robot with a keyboard, mouse, data-glove and a head mounted display (HMD). Through the application the user is able to control a simulated robot in a combat scenario by selecting only one of the following two combinations of input and output devices: 1) keyboard, mouse, and monitor; and 2) data-glove and HMD. The key hardware components used were the 5DT Ultra data glove, and the Oculus Rift HMD, with WorldViz Vizard used for the VR environment. To assess user preferences of input and out devices, an experiment was conducted where participants operated the virtual robot within the VR environment using both control modes, with each mode selected in separate sessions. The result of a post analysis survey discusses the participants' view on the usefulness of the application.

The rest of the paper is structured as follows. Section II, briefly describes the related work. Section III, describes the details of implementation of this study. Section IV, discusses the evaluation and results of the study. Section V, discusses drawn conclusions and proposed future work.

II. RELATED WORK

This section gives general background of the present state of using head mounted display (HMD) technology, data glove technologies, the use of data-gloves for control and communication applications, teleoperation of robots using virtual reality techniques, and finally addresses some of the technical challenges associated with teleoperations of real robots.

A. Head Mounted Displays

In recent years, significant developments have occurred with HMD technology. HMDs are now used for Mixed Reality (MR) and Augmented Reality (AR) applications offering up significant characteristics that handheld and spatial displays cannot. HMDs provide sensors to visual, auditory, and olfactory sensations, thus augmenting sensations of a user's perception. HMDs are personal devices with the information presented privately to the user and hidden from others [2]. In 2012 a prototype HMD, precursor to the Oculus Rift, was developed by Palmer Lucky for virtual reality applications, and the HMD attracted the attention of industry leaders in viewing it as a low cost device capable of providing a high-fidelity experience in VR applications using common smart phones. One of the most attractive features of the design is its wide viewing angle, which significantly increased the sense of immersion in comparison to existing HMDs at the time [3]. Tele-operated robots have successfully used HMD motion to control the pan and tilt orientation of cameras and for providing smooth camera operations [4].

Much research focuses on stereoscopic depth vision and

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how such an application should be designed. Stereoscopic vision enhances the user's immersion into the virtual or tele-world. Stereoscopic depth perception requires using two cameras, and therefore greater immersion is likely to occur. The use of CAVEs and HMDs support stereoscopic display, and in the case of tele-robotics, HMDs is the more likely approach of implementation [5] [6].

B. *Data Gloves*

Data gloves are frequently used as input to computing systems to interpret human hand gestures, with researchers actively exploring many design approaches. The most common control mode of steering a robot to manipulate objects for teleoperation is through the use of a data glove. However, other control methods are under investigation. For example, the use of a control peg designed to look and feel like the actual object that the robot will physically manipulate for the user, with the peg designed with sensors to determine its position and orientation [7]. A data glove system is composed of multiple sensors, electronics for microcontroller processing and control, and physical sensors support worn on the user's hand. Typically, gloves are made of Lycra fabric with the sensors sewn in, but other materials such as leather, cotton, and plastic have been used [8].

C. *Tele operated Robots using Virtual Reality*

There is extensive interest in the design of mobile tele-robotics systems using VR. For example, remote controlled robots in combat situations is explored in all of the US armed forces from the Navy, Army and Air [9] [10]. Online universities are researching ways to support remote laboratories and tele-presence robotics to enhance their offering for distance learning students [11]. Research has been ongoing to perform telepresence operations over a mobile robot controlled with a Noninvasive Brain–Computer Interface (BCI) using electroencephalogram-based brain-actuated sensors with the BCI can detecting brain activity and decoding the user's intentions which are then transferred and executed on the remote robot [12]. VR may be considered the best human to machine interface to date, and a tele-operated robot can act as an extension of the human operator. Until artificial intelligence further matures, robots will be tele-operated by humans, with VR being the presentation layer to the human to map the robot's environment to the user in an attempt to give the user the feeling of presence where the robot is physically located [13].

III. IMPLEMENTATION AND USER STUDY

This section discusses the hardware, and the VR software used to carry out the experiment. It then provides details on the general test setup, the procedures, and the post-analysis survey to run the experiment. Finally, it discusses the results of the post-analysis survey.

A. *Software and Hardware*

Figure 1. Oculus Rift

Figure 2. 5DT Data-glove

The virtual reality application was developed to simulate tele-operating a robot in combat with a primary focus to explore user preferences in using the 5DT data glove and Oculus Rift shown in Fig 1 and Fig 2. A PC workstation or laptop running Windows 7 was used for software development. The virtual reality engine used was WorldViz Vizard version 5. Various 3D objects were created using SketchUp by Tremble Navigation, Ltd. The final application written in Python is a culmination of Vizard example scripts, a VR environment developed by Bowie State University, and custom software scripts developed specifically for this study.

The simulated environment provides a scenario where the simulated robot is immersed into a hostile environment encountering multiple opponents that are trying to destroy it with weapons fire. Upon being hit by weapons fire, the robot will sustain damage by losing health points. The mission of the robot is to maneuver and destroy the enemy opponents, and then locate the hostage and take them to safety. The robot can destroy the enemy avatars by aiming and firing its weapon on them.

B. *Combat VR Environment*

The environment is set up for the user to navigate throughout with the objective to destroy several combatant avatars. The combatants can be destroyed by the operator aiming and firing its weapon at the combatants. Once the combatants are hit by a round they are destroyed. Fig 3 shows an image of the environment with enemy soldiers, and the crosshair in the middle of the screen. Fig 4 shows the red-black fireball being fired at the user atop the tower in top right corner. Fig 5 shows a combatant being targeted with the crosshair before the weapon is fired.

Figure 3. Enemies with crosshair in middle of screen

Figure 4. Red-black fireball fired at user, top right

Figure 5. Targeting enemy with crosshair before firing

Once the user destroys all of the combatants, they can safely search for and locate a hostage avatar to carry them to safety. The static objects in the environment are the buildings and scenery the user operates within. The dynamic objects in the VR are the combatant avatar's that can fire ammunition at the robot and damage its health.

C. User Study Setup

As a preliminary study, a group of 10 persons were solicited to partake in the experiment. The participants consisted of 6 computer science graduate students, 3 family members, and 1 friend. None of the participants had significant experience using immersive interfaces such as the Oculus Rift and the 5DT data glove. However, all users had experience using non-immersive interfaces.

The test was designed to measure user preferences of immersion verses non-immersion control. To compare user preferences, the user was required to control the robot in two distinct modes of operation. The non-immersive mode required using the Keyboard, Mouse, and Display to manipulate the robot and to fire the weapon. The immersive mode allowed navigation and control using the Data-Glove and the HMD. Table I shows the functionality provided via the keyboard and mouse. In this mode the user can fire the weapon, walk forward, turn left, turn right, and pick up or put down the hostage to carry them safety. The Mouse Control is provided for overlaying the crosshair gun target on the opponent to be fired upon.

TABLE I. Keyboard and mouse controls

Key	**Action**
Space-bar	Fire weapon
Up-arrow	Walk-forward
Left-arrow	Turn-left
Right-Arrow	Turn-right
p key	Pickup/Putdown-hostage
Left-Mouse click	Fire-weapon
Down-Arrow	Fire-Weapon
No-key-pressed	Stop

Table II shows the gestures and controls using the Oculus Rift HMD and the 5DT data-glove. The data glove and HMD combination provides the same functionality as provided by the keyboard and mouse mode. When used in this mode, the Oculus Rift HMD will allow the user to look around in all directions as they navigate with the glove. For aiming the weapon, the user will see at the center of the display a crosshair cursor, and as they move their head the crosshair will always remain in the center of the scenery. They can move their head until a target is overlaid with crosshair, and at that point they can fire the weapon at the target.

TABLE II. 5DT Ultra Data Glove and Oculus Rift Controls

5DT Glove-Gesture	**Action**
Index-And-Little-Finger-Point	Fire-Weapon
Little-Finger-Point	Fire-Weapon
Index-Finger-Point	Walk-forward
Fist	Pickup/Putdown Hostage
Flat-Hand	Stop
Oculus HMD - Gesture	**Action**
Turn head left	Turn-Robot-Left
Turn head right	Turn-Robot-Right

D. Experimental Procedure

This section briefly describes the procedure used to run the experiment. First each user was seated in front of a computer configured with the VR application. Then the user was directed to begin operating in the VR in mode 1. In mode 1 the user was shown how to operate the application using only the keyboard mouse, and monitor. The user was then given 2 minutes to operate. Following mode 1, the user was then shown how to operate in mode 2 using the data glove and HMD. In this mode the user had to stand up with the data glove and HMD worn, so that they had the freedom to rotate their body for the HMD navigation. The user was then given 2 minutes to operate. Following the experiment, the user was required to take the post analysis survey. The experiment took about 10 minutes for each participant to complete.

IV. EVALUATION AND RESULTS

This section discusses the evaluation questions, the collected data, and a summary of the results.

A. Survey Questions and Data

Table 3 lists the post analysis survey questions and summarizes the user responses. The first two questions request the user age and gender. The remaining questions were designed to measure the overall feelings the user had towards operating in the immersive verses non-immersive environment.

TABLE III. Survey Questions and Results

Questions	Results – Raw Data		
1. What is your age?	18-24	5	50%
	25-34	3	30%
	35-44	0	0%
	45-54	2	20%
	55-64	0	0%
	65-above	0	0%
2. What is your gender?	Male	5	50%
	Female	5	50%
3. Can this application be used for educational or training purposes in a remote robot combat control situation?	Poor	0	0%
	Fair	2	20%
	Good	3	30%
	Very Good	4	40%
	Excellent	1	10%
4. Can this application be used as a substitute for controlling a remote robot as opposed to physically being there?	Poor	0	0%
	Fair	2	20%
	Good	3	30%
	Very Good	5	50%
	Excellent	0	0%
5. Do you think viewing this virtual reality application for a remote robot control simulation will help during a real-time (actual) situation?	Poor	0	0%
	Fair	2	20%
	Good	4	40%
	Very Good	3	30%
	Excellent	1	10%
6. How did you like using the 5DT data glove?	Poor	0	0%
	Fair	4	40%
	Good	1	10%
	Very Good	2	20%
	Excellent	3	30%
7. How did you like using the Oculus HMD?	Poor	0	0%
	Fair	0	0%
	Good	3	30%
	Very Good	3	30%
	Excellent	4	40%
8. How did you like the non-immersive mode? (Keyboard & Mouse control)	Poor	0	0%
	Fair	1	10%
	Good	7	70%
	Very Good	1	10%
	Excellent	1	10%
9. How did you like immersive mode? (Glove and HMD control)	Poor	0	0%
	Fair	1	10%
	Good	1	10%
	Very Good	3	30%
	Excellent	5	50%
10. Which mode did you MOST prefer when controlling the robot?	non-immersive	1	10%
	immersive	9	90%
11. Answering this question is required to complete the survey. Please make recommendations or suggestions to improve on this research	Text Entry / See discussion for results		

B. Data Implications

As seen in the Table 3 data, the population consisted of 50% male and 50% female. Eighty percent (80%) of all users were age 34 or younger, and the remaining 20% were 45 to 54 years old.

Fig 6 shows the mean and standard error bars of the user responses from questions 3 through 9 which measure how the users feel about using immersive verses non-immersive environment. Overall, one can see that the users were generally receptive to this application. The users were particularly favorable to operating in the immersive mode as indicated by responses to question 9.

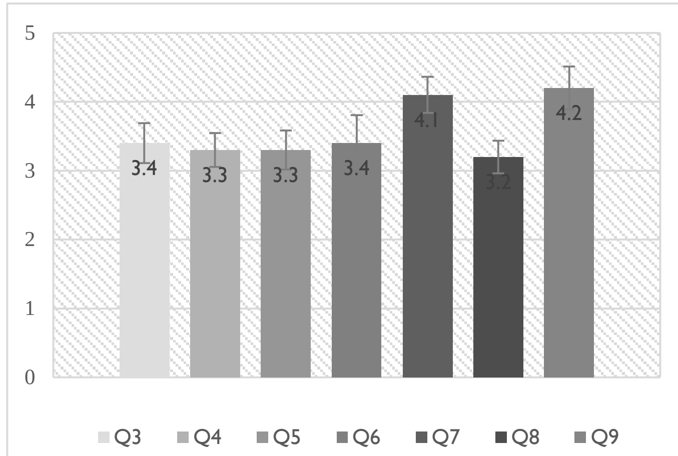

Figure 6. Results of questions 3 through 9 – with mean and error bars

The overall summary of the data suggests that most users feel that this application could be a good tool for educational and training purposes for teleoperation of a robot. Most users felt that the 5DT data glove is a good device to use for robot control, and most users felt that the Oculus HMD is a very good device for robot visualization control. Finally, the users felt that the non-immersive mode is a good way to control the robot, however they felt the immersive mode is better. This is further shown by the user responses to question 10 where 90% of the users preferred the immersive mode over 10% preferring non-immersive.

Out of the ten participants, five took time to answer the survey question number 11 that asked them to make recommendations or suggestions to improve on this research. For non-immersive related comments, one participant expressed interest in changing the behavior of the arrow keys to make the left and right turning actions smoother. This was in response to the software design implementing 1-degree discrete resolution positions during turning which caused a jittering effect. They also were unhappy with not being able to move forward while turning right and left, as the design only allowed for one navigation motion at a time. For the immersive mode, one participant expressed that the Oculus graphics display should be clearer, alluding to an interest for greater luminance and pixel resolution of the Oculus Rift. Two respondents complained about the data glove accuracy because of incorrect glove readings leading to invalid or incorrect behavior of the robot under control. This problem was due to the 5DT data glove occasionally reporting improper gesture codes, possibly an indication of malfunction. Regarding more general positive responses, one participant expressed that the research was thought provoking and provided for interactive simulation, and another participant expressed that the overall experience with the simulation was really fun.

V. LIMITATIONS OF THIS STUDY

This section briefly addresses some of the shortcomings of this study, and provides suggestions for improvement. As noted by user feedback from question 11, there were significant shortcomings in the hardware and software performance. Therefore, future effort should use more accurate devices, and provide a more user friendly software interface. Another enhancement would be to design a test to measure and compare user performance accuracy across both environments to determine which provides for better performance to the user. A significant improvement for future study would be to sample a broader range of users, and take into account their varying levels of experience using immersive verses non-immersive platforms. This would allow an assessment of how user experience impacts performance. Finally, a significant limitation was the small user sample size, thus for greater statistical significance of results, a larger sample size is required.

VI. CONCLUSIONS

A background survey has been provided to discuss some fundamental requirements of using a VR environment for human teleoperation of robots in a combat or hostile environment. A complete VR prototype system was implemented to carry out an experiment where users could provide feedback on their view of the effectiveness of VR immersion verses non-immersion to control a simulated robot. The results of the post-analysis survey were discussed in detail, and the general conclusion drawn from user feedback was that it is better to use VR immersion to control a simulated teleoperated robot in a hostile environment, therefore, providing a hint of evidence that telerobotic control is best performed using VR immersive technology. This small study provided useful information on requirements to improve upon such an effort if it were to be conducted on a larger study group.

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REFERENCES

[1] L. Srinivasavaradhan, G. Chandramouli, and A. G. Maniprashanna, "7th sense. A multipurpose robot for military", Perspective Technologies and Methods in MEMS Design, MEMSTECH, 5th International Conference, pp 158-160, April 2009.

[2] K. Kiyokawa, "Trends and vision of head mounted display in augmented reality", IEEE International Symposium on Ubiquitous Virtual Reality, pp 14-17, August 2012.

[3] S. M. LaValle, A. Yershova1, M. Katsev, and M. Antonov, "Head tracking for the Oculus Rift", IEEE International Conference on Robotics & Automation (ICRA) Hong Kong Convention and Exhibition Center, pp 187-194, May-June 2014.

[4] H. Ogiya, S. Ishida, M. Yasuda, and N. Matsuhira, "Teleoperation via head-mounted display motion with the Robot Service Network Protocol", SICE Annual Conference 201, pp 1115-1117, July 2015.

[5] G. Moreau, "Visual immersion issues in Virtual Reality: a survey", 26th Conference on Graphics, Patterns and Images Tutorials, pp 6-14, August 2013.

[6] S. Kang, W. Lee, M. Kim and K. Shin, ROBHAZ-rescue: rough-terrain negotiable teleoperated mobile robot for rescue mission", Proceedings of the 2005 IEEE International Workshop on Safety, Security and Rescue Robotics Kobe, Japan, pp 105-110, June 2005.

[7] K. Kukliński, K. Fischer, I. Marhenke, F. Kirstein, M. V. aus der Wieschen, D. Solvason, N. Kruger, and T. R. Savarimuthu, "Teleoperation for learning by demonstration: Data glove versus object manipulation for intuitive robot control", Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT), 2014 6th International Congress, pp 346-351, October 2014.

[8] L. Dipietro and A. M. Sabatini, "A survey of glove-based systems and their applications", Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on (Volume: 38, Issue: 4), pp 461–482, 20 June 2008.

[9] T. Zielinska, "Control system of walking robot", IEEE, Second Workshop on Robot Motion and Control Internal Workshop, pp 225–230, October 2001.

[10] C. E. Agüero, N. Koenig, I. Chen, H. Boyer, S. Peters, J. Hsu, B. Gerkey, S. Paepcke, J. L. Rivero, J. Manzo, E. Krotkov, and G. Pratt, "Inside the virtual robotics challenge: simulating real-time robotic disaster response", Automation Science and Engineering, IEEE Transactions on (Volume:12, Issue: 2), pp 494–506, 19 January 2015.

[11] M. Denojean-Mairet, Q. Tan, F. Pivot, and M. Ally, "A ubiquitous computing platform - affordable telepresence robot design and applications", Computational Science and Engineering (CSE), IEEE 17th International Conference, pp 793–798, December 2014.

[12] C. Escolano, J. M. Antelis, and J. Minguez, "A telepresence mobile robot controlled with a noninvasive Brain–Computer Interface", Systems, Man, and Cybernetics, Part B: Cybernetics, IEEE Transactions on (Volume: 42, Issue: 3), pp 793–804, December 2011.

[13] D. Cheng-jun, D. Ping, Z. Ming-lu, and Z. Yan-fang, "Design of mobile robot teleoperation system based on virtual reality", Proceedings of the IEEE International Conference on Automation and Logistics Shenyang, China, pp 2014–2019, August 2009.