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Analysis of VR Usability in Mobile Manipulator Teleoperation

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***Abstract*—Hazardous materials incident responding and explosive ordnance disposal (EOD) are two of mobile manipulators' most common deployment areas. Most of the time, these incidents happen in open environments and even ruin structures. Therefore, teleoperation is still the dominant robot control method. However, a direct line of sight can be limited. This study includes an experiment demonstrating a virtual reality device application in a real-world mobile manipulator EOD mission. The result support the feasibility of teleoperating a mobile manipulator using VR to complete complex missions.**

***Index Terms*—VR, teleoperation, mobile manipulator**

I. INTRODUCTION

In response to hazardous material (HAZMAT) incidents and explosive ordnance disposal (EOD) tasks with high risk levels, which can potentially cause harm to the human first-responders, a defensive response strategy is usually preferred. However, in certain HAZMAT and EOD incidents, an offensive strategy is needed to isolate or stabilise an incident and prevent a chain reaction [1]. Therefore, having robots, specifically mobile manipulators, replacing human labour in these cases can reduce the risk level for human responders. However, the complexity of missions and the uncertainty of the open environment creates hardships for autonomous systems and makes teleoperation the first choice of control method. Therefore, an efficient teleoperation system is critical for mission success.

Furthermore, in these applications, the robot operator needs to keep a safe distance from the subject and subsequently does not have a direct line of sight. Therefore, the visual feedback needs to be provided to the robot operator in an alternative form. RGB-D cameras can represent both coloured 2D imaging and distance data, and VR can efficiently present multiple forms of information to the operator [2] without limiting the operator's orientation and body movement.

Among these teleoperation technologies, the gamepad is used with the advantage of being low cost. However, more recent studies have investigated the approach of using human body movements to teleoperate a robot with motion capture technology [3]. Compared to the traditional gamepad, the motion capture technology has advantages in manipulation movement [4], therefore, it is more suitable for EOD tasks [5]. On the other hand, compared to the wheeled manipulator, the quadruped manipulator [6] can conquer a broader range of terrain and structures.

In this study, we have built the experiment setup based on our previous work [6], where a legged manipulator and a motion capture system were integrated for teleoperating locomotion and manipulation movement simultaneously. By introducing an RGB-D camera on the robot and a VR system for the teleoperator to perceive the visual feedback from the robot, the system can perform tasks where direct line of sight is not available. Three volunteers performed a EOD task experiment with direct line of sight and then using the proposed VR system. The performance is compared through completion time, and usability is evaluated through participant feedback.

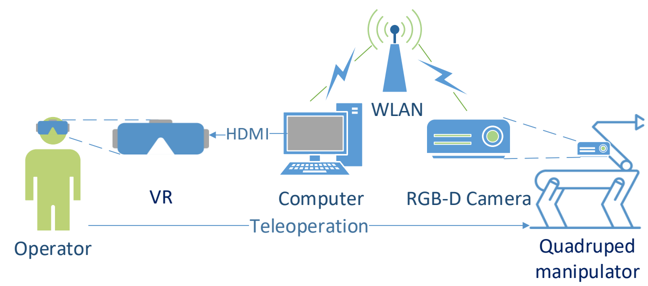

Fig. 1: The structure of the visual feedback system used in the experiment.

II. SYSTEM OVERVIEW

As illustrated in Fig. 1, the developed remote visual feedback system is composed of three parts, the RGB-D camera on the robot, the processing computer, and the VR device.

A. RGB-D Camera

In this study, an Intel RealSense D435 RGB-D camera is installed on the side of the robot arm for a third-person view. The camera is mounted on the base joint of the arm, where it is coupled with the yaw rotation of the arm. The camera generates a coloured 3D depth point cloud from a 2D colour image and the depth sensor. This information is then sent to the computer.

B. Processing Computer

In the proposed system, a computer collects input from the camera through a wireless LAN (WLAN) network, as shown in Fig. 1. Then, the computer combines the coloured 3D depth point cloud with the directly mapped 2D image placed overhead. The combined signal is then sent to VR together.

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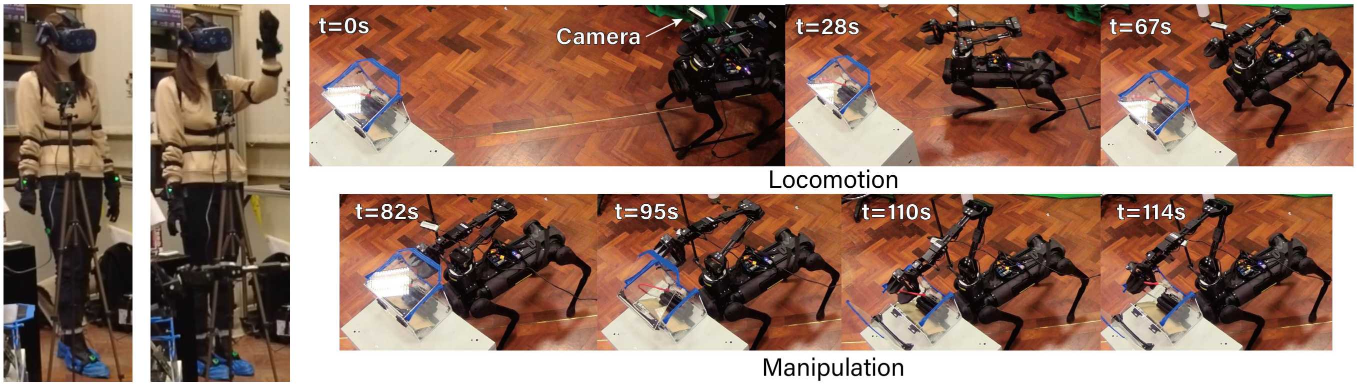

(a) (b) (c)

Fig. 2: The operator uses (a) lower body for locomotion and (b) upper body for manipulation control of (c) a legged manipulator in an EOD experiment.

C. VR

Since the computer and operator are both located in a safe area, the system uses a HDMI cable to connect the computer and VR device to reduce delay and increase system stability. The user-end VR is the HTC VIVE Pro headset. The operator can rotate to any direction compared to facing a fixed screen. In the VR view, both depth point cloud and 2D image are displayed to the user.

III. Experiment Process

As shown in Fig. 2, participants use a motion capture suit and a VR device to teleoperate the robot completing an EOD task. The EOD task requires the robot to start from the starting position and walk towards the target "bomb" box, then open the box with the robot arm, and finally pull out the red wire from the top of the "bomb" to disable it. A previous study has experimented with a direct line of sight [4], where the times that the users completed the same EOD task will be compared with the results from this study to assess. Three participants were randomly selected to perform the EOD task again using VR. This research evaluates their performance through completion time and participant feedback.

IV. VR Usability Result

This experiment clarified the VR system's applicability in a complex mission with a teleoperated mobile manipulator robot. The time for each participant's three attempts and their averages are shown in Table I. To highlight, although the average VR time to complete the task was longer than the direct line of sight time, the application for VR environments is where line of sight is impossible. Both users show improvement in performance as the number of trials increases, and the time tends to become closer to that of direct sight.

In the later interviews, no participant experienced any dizziness or discomfort during the task. One indicates that the VR helped them imagine being the robot and had a better user experience. However, the same participant finds the depth point cloud in VR is not as helpful as expected: "I found myself focusing more on the 2-D camera image than the depth view, as I found it easier to follow." The low resolution of the depth point cloud can cause this poor user experience.

TABLE I: Participants' task time through direct sight and VR

Time (sec)	Participant1				Participant 2			
	1st	2nd	3rd	Avg	1st	2nd	3rd	Avg
Direct sight	72	52	57	**60**	97	96	79	**91**
VR	135	114	85	**111**	145	128	101	**125**

Both participants pointed out that the camera installation and position needed improving: "I would also say that the camera position is not great. It is too close to the front of the robot. Suppose the camera is positioned more towards the back of the robot (similar to a chasing view) and on a more solid support frame would make it easier."

V. Conclusion

This experiment result proved the feasibility of teleoperating a mobile manipulator using motion capture technology with visual feedback through a VR to complete complex missions, with the example of an EOD task. However, from participants' feedback, a camera with high depth point cloud resolution and stabiliser can improve user experience and performance in mobile manipulator operations.

Further research will improve the current system based on the feedback received from participants. A camera with a zoomable lens that can zoom out during locomotion, and zoom in for manipulation may achieve higher system performance.

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