A 6-DOF Telexistence Drone Controlled by a Head Mounted Display

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Figure 1: A telexistence drone is controlled by a user with our motion mapping mechanism and provides immersive viewing experience to the user in real time. As the user rotates his head, the drone rotates accordingly and transmits the recorded frames of an outdoor scene back to the HMD.

ABSTRACT

Recently, a new form of telexistence is achieved by recording images with cameras on an unmanned aerial vehicle (UAV) and displaying them to the user via a head mounted display (HMD). A key problem here is how to provide a free and natural mechanism for the user to control the viewpoint and watch a scene. To this end, we propose an improved rate-control method with an adaptive origin update (AOU) scheme. Without the aid of any auxiliary equipment, our scheme handles the self-centering problem. In addition, we present a full 6-DOF viewpoint control method to manipulate the motion of a stereo camera, and we build a real prototype to realize this by utilizing a pan-tilt-zoom (PTZ) which not only provides 2-DOF to the camera but also compensates the jittering motion of the UAV to record more stable image streams.

Index Terms: Telexistence, Head Mounted Display, Unmanned Aerial Vehicle, 3D interaction, Virtual Reality

1 INTRODUCTION

Telexistence is a new concept of virtual reality (VR), which allows humans to interact with remote environments rather than their current location in real 3D circumstance. Benefiting from having sufficient freedom and the possibilities for monitoring extensive space like sky and mountain, an unmanned aerial vehicle (UAV) shows superior ability compared with other distal robots especially in remote tasks. In view of this, researchers are more interested in developing a UAV telexistence system by employing different natural user interfaces, like gesture and speech, with a 3D display device [1].

It is not trivial to design and implement an interface to intuitively and naturally manipulate a UAV by an HMD. We propose two contributions on this. Firstly, in order to provide unlimited space for users [2], we adopt a translation-to-velocity (rate-control) strategy by an adaptive origin update (AOU) scheme to dynamically change the coordinate system of the user, which makes it easier and more precise to control the hovering and flying state of the UAV. Secondly, since a traditional UAV cannot provide full 6-DOF to the cameras on it, previous techniques do not consider the controlling of rotations on pitch and roll directions [3]. Different from them, we work on the full 6-DOF and develop a prototype by adding a pan-tilt-zoom (PTZ) on the UAV to freely rotate the cameras on the pitch and roll directions and thus provide 360° viewing experience.

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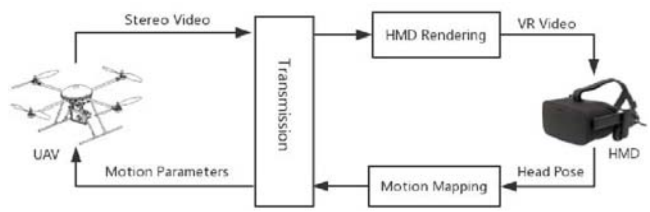

Figure 2: Our HMD-based UAV telexistence system.

2 METHODS

The entire architecture of our HMD-based telexistence drone system is shown in Fig. 2. We develop a customized quadcopter which consists of a capture and a transmission module. A stereo camera with fisheye lenses is utilized to capture live-streaming 3D video content. The PTZ used to carry the stereo camera gives 2-DOF (pitch and roll) and the rest 4-DOF (three translations and the yaw rotation) are given by the UAV. So we have the full 6-DOF to achieve any desired viewpoint in telexistence.

Basic Mapping Machanism. The forward and left directions of the HMD are considered as the positive directions of the x-axis and y-axis, respectively. The position vector $\vec{c}$ starts from the origin and ends at the HMD's current position. Within a predefined distance r from the center, we only map the rotation of the HMD to that of the camera when the UAV keeps hovering. Otherwise, the UAV will always fly in the direction of $\vec{c}$ and its speed is $k * (|\vec{c}| - r)$. The factor of gain control k is set to 1 to balance the usability and accuracy of the control.

Adaptive Origin Update (AOU). When stepping back into the circle, it is difficult for the user to perceive the origin precisely, especially after staying outside the circle for a long time. This may

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Table 1: Statistics of different methods on Time, Distance, Score and Workload.

Methods	Time			Distance			Score			Workload		
	Mean	*SD*	*CI*	*Mean*	*SD*	*CI*	*Mean*	*SD*	*CI*	*Mean*	*SD*	*CI*
Modified Flying Head(MFH)	334.86	184.44	87.68	1018.48	515.71	245.10	77.17	0.64	0.30	4.65	0.98	0.47
Head Rotation(HR)	230.12	115.51	45.28	794.42	253.79	99.48	77.26	0.78	0.31	2.30	0.58	0.23
Flying Plane(FP)	211.47	95.96	37.62	659.19	239.17	93.75	77.23	0.67	0.26	3.23	0.89	0.35
Ours	**138.09**	46.38	17.73	**540.59**	265.68	102.1	**77.76**	0.69	0.27	**1.46**	0.45	0.17

Table 2: Statistics of our method w/o AOU on Time, Distance, Score and Workload.

Methods	Time			Distance			Score			Workload		
	Mean	*SD*	*CI*	*Mean*	*SD*	*CI*	*Mean*	*SD*	*CI*	*Mean*	*SD*	*CI*
without AOU	25.24	10.23	6.4	118.28	22.05	13.67	31.04	7.21	4.47	2.5	0.63	0.39
with AOU	**19.48**	3.24	2.01	**98.77**	5.02	3.11	**32.03**	7.47	4.63	**2.21**	0.83	0.51

cause an unwanted teleoperation. This drawback could be overcome with a clutching mechanism, haptic aids or visual hints, however, these solutions require auxiliary setups.

Even though it is difficult to perceive the origin, the user could always perceive a rough direction of the physical circle area according to the sense of the flying direction of the UAV by the images in the HMD. Based on this observation, we propose an Adaptive Origin Updating (simplified as AOU) scheme. When the user steps back inside the circle and stays still, we reconfigure the origin as the current position of the HMD. This enables both freely viewing for the user and easy control for the UAV. Additionally, we extend this scheme to a braking mechanism which means if the user moves far away from the physical circle, the origin is allowed to be updated as soon as stepping towards the inverse flying direction of the UAV, even though the user has not come back to the circle. This could handle some emergencies once the user loses the controlling of the UAV in the case of high speed flying.

Full Viewpoint Control. Our telexistence drone system realizes a full 6-DOF motion mapping containing translations in all directions of the UAV and flexible rotations of the stereo camera. Besides the 4-DOF motion provided by the drone itself, we utilize a PTZ to enable the pitch and roll rotations for adjusting the viewpoint when needed. On the other hand, in view of the intense jittering in a UAV system, the user could obtain a better telexistence experience with the stability augmentation of PTZ, since the PTZ could perceive the jittering of the UAV and compensate the jittering to a certain extent by its own motions.

3 Experiments

We build a simulation system and a real prototype to validate our proposed technique. We compare our motion mapping mechanism with five state-of-the-art methods and then evaluate the effectiveness of our AOU scheme.

Comparisons. Twenty-five participants are recruited to experience the user study. The performance and perception of workload on each compared algorithm are listed in Table 1. The statistics are shown by *Mean*, Standard Deviation (*SD*) and 95% confidence intervals (*CI*) values on different dimensions. The workload is calculated by the rating of four subjective assessments which are related to mental demand, physical demand, effort and frustration from the users. The performance of MFH is far behind our method on this task, because the position control method is not applicable to UAV telexistence within limited motion space in spite of its naturalness. The performance of HR relies on the rotation of HMD to control the UAV, which may hinder the free viewing experience of users when they look for flying directions. Although the drawback can be overcome based on FP controlling, the common translation-to-velocity mechanism still can not achieve omni-directional motion mapping. Our AOU scheme and the full viewpoint control overcome the shortcomings of other mechanisms and provide a more natural and intuitive interaction style, demonstrated by the user study.

Evaluations. Table 2 shows the performance with and without AOU. On time and distance dimensions, the rate control method with AOU owns better performance than the one without AOU. On the score dimension, there is no obvious evidence for a difference between the two methods as AOU is not designed for fine-tuning directions or positions. We see that the method with AOU has lower workload than the one without it. This indicates that AOU makes it easier and more effective for users to complete the task, because there is no need to identify the initial position to get the origin in any cases.

4 Conclusion

We have developed a 6-DOF telexistence drone to present free viewpoint control and 3D immersive viewing experience to a user. In the future, we would like to label some data and train a model to distinguish the meanings of users motions. Better performance is expected to be achieved.

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