

A 360° Video-based Robot Platform for Telepresent Redirected Walking

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ABSTRACT

Telepresence systems have the potential to overcome limits and distance constraints of the real-world by enabling people to remotely visit and interact with each other. However, current telepresence systems usually lack natural ways of supporting interaction and exploration of remote environments (REs). In particular, the usage of single webcams for capturing the RE provides only a limited illusion of spatial presence. Furthermore, typical movement controls of mobile platforms in today's telepresence systems are often restricted to simple interaction devices. For these reasons, we introduce a prototype of a 360° video-based telepresence system consisting of a head-mounted display (HMD), a 360° camera, and a mobile robot platform. Considering the heterogeneous layouts between the user's local environment (LE) in which the user's motions are tracked and the RE, redirected walking (RDW) technology and different gains are applied to this system to allow users to explore a much larger RE than the LE. With this setup, users can get a 360° full-view rendered view on the HMD from the RE, and explore it by the most intuitive and natural way, e. g., by real walking in the user's LE, and thus controlling movements of the robot platform in the RE.

CCS CONCEPTS

• **Information Interfaces and Presentation** → Multimedia Information Systems; Artificial, augmented, and virtual realities; • **Computer Graphics** → Three-Dimensional Graphics and Realism; Virtual reality;

KEYWORDS

Virtual reality, telepresence, 360° camera, redirected walking.

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1 INTRODUCTION

Telepresence refers to a set of technologies, which aim to convey the feeling of being in a different place than the space where a person is physically located [15]. The ideal goal for teleoperation is that users feel as if they were actually present at the remote site during the teleoperation task [15]. Therefore, telepresence systems should allow humans to move through the remote environment (RE), interact with remote artifacts or communicate with the remote people. Such technology nowadays is becoming increasingly common in our daily lives and has enormous potential for different application domains ranging from business, tourism, meetings, entertainment to academic conferences [7, 16], education [8, 11], and remote health care [1, 4]. However, current telepresence systems usually lack natural ways of supporting interaction and exploration of REs. In particular, most current telepresence platforms consist of mobile webcams with speakers and microphones. As a result, the usage of single webcams for capturing the RE provides the users with a very narrow field of view and a limited illusion of spatial presence. Both issues limit the sense of presence of teleoperators [15]. Furthermore, the deficiency of visual information about the RE can lead to a high error-rate for teleoperation tasks and remote interactions [15]. In addition, typical movement controls of mobile platforms in today's telepresence systems are often restricted to simple interaction devices, such as joysticks, touchpads, mice or keyboards. Since these devices require the operator to use their hands in order to control the mobile platform, the hands are not free to perform other tasks. This may decrease the naturalness, task performance and overall user experience [15].

In order to address these limitations and challenges, this paper introduces a prototype of a 360° video-based telepresence system, which aims to provide the local user with a more natural and intuitive way to explore and visit a RE.

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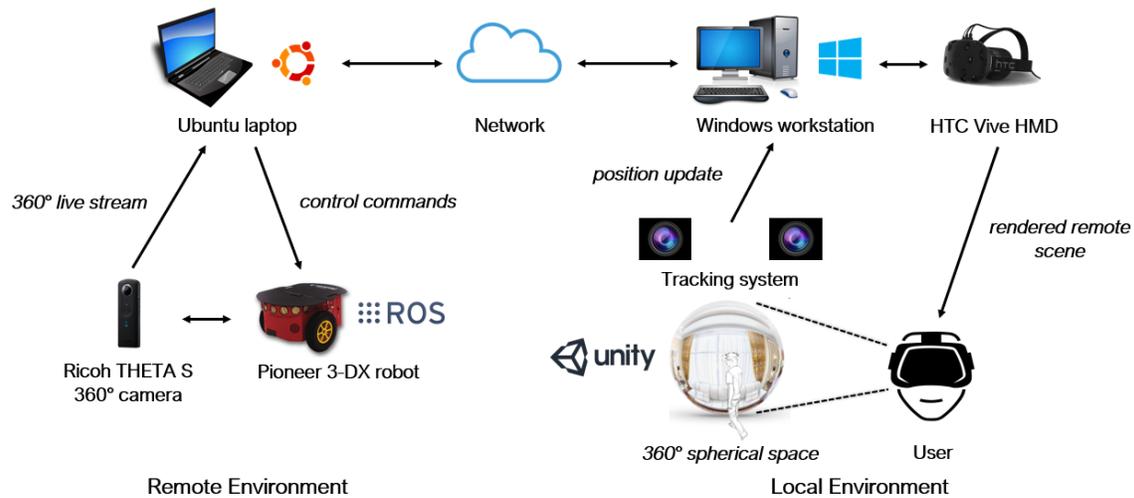


Figure 1: Components and structure of 360° video-based telepresence system: On the remote side, a mobile robot equipped with a 360° camera captures a 360° full-view live stream and then transmit it to the local side via a communicating network. On the local side, the received live stream is rendered and projected inside a spherical space and displayed on the user’s HMD. The user wearing an HMD teleoperates the remote mobile robot moving through the RE by means of real walking in the local tracked space.

2 SYSTEM DESIGN

Figure 1 illustrates the basic components and structure of 360° video-based telepresence system. A 360° full-view camera and an HMD form the basis of this 360° video-based telepresence system, which aims to improve the sensation of presence and the user’s spatial perception compared to a typical webcam and its narrow 2D view. A mobile robot equipped with a 360° full-view camera serves as physical agent of the local user at the remote side. The mobile robot provides the 360° camera with mobility which makes it possible for the 360° camera to go through the whole RE. The 360° camera captures a full-view live stream from the RE and then transfers the information of visual scene to the LE via a communication network in real time. The system control and data exchange between the 360° camera and the mobile robot on the remote side are implemented on a laptop.

At the local side, a real-time virtual environment (VE) is reconstructed and rendered in Unity3D using the received live stream from the RE. An HMD is provided to the user in the LE to display the reconstructed virtual representation of the RE, which can induce a higher sense of presence by displaying a wider perspective compared to a simple screen or a monitor. With a continuous update of live stream from the RE, the user wearing the HMD in the LE perceives a 360° full-view immersive experience to explore and visit the RE in real-time. All the reconstruction and rendering work on the local side are performed on a graphics workstation. During the interactive process, the user’s movements in the LE are detected by a set of tracking system in real-time and mapped to the remote side. The update of the user’s position and orientation in the LE controls the robot’s movements in the RE. This way, the user can drive the mobile robot through the RE and move to the location by

means of real walking in the LE. Compared with other means of movement control for telepresence robots, real walking in the LE is more natural and intuitive when the user needs to travel in the RE from one location to another [6, 13]. Since the position of the camera in the RE is determined and updated according to the position of the user in the LE, this approach provides the most consistent and intuitive perception of motion in the target environment, while releasing user’s hands for other potential interactive teleoperation tasks as well.

One major problem of this approach is that it requires that the layouts of local and remote space are more or less identical. In most cases, however, the available local tracked space is smaller than space in the RE, which the user wants to explore, and furthermore, local and remote environments typically have completely different spatial layouts. Therefore, we introduce the redirected walking (RDW) method for the 360° video-based telepresence system. Redirected walking is a technique for virtual reality (VR) to overcome the limits and confined space of tracked room [10]. While RDW is based on real walking, the approach guides the user on a path in the real world, which might vary from the path the user perceives in the VE. RDW can be realized by manipulations applied to the virtual camera, causing users to unknowingly compensate for scene motions by repositioning and/or reorienting themselves [14]. RDW without the user’s awareness is possible because the sense of vision often dominates proprioception [2, 3]. In other words, the visual feedback that the user sees on the HMD corresponds to the motions in the VE, whereas proprioception and vestibular system are connected to the real world. When the discrepancy is small enough, it is difficult for the user to detect the redirection, which would lead to the illusion of an unlimited natural walking experience [9, 12].

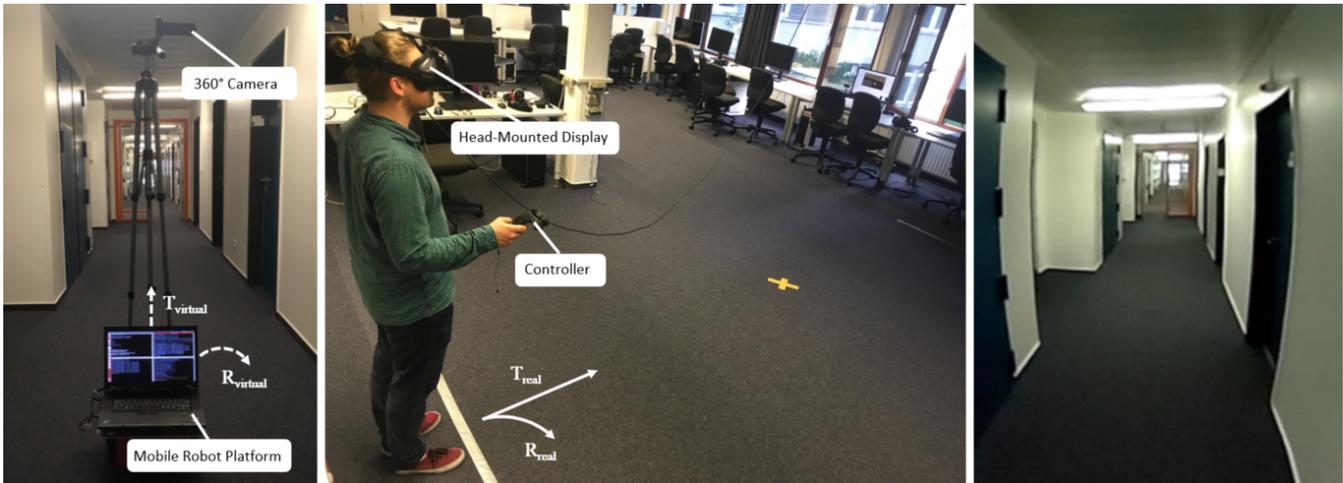


Figure 2: Application of RDW technology in 360° video-based telepresence system: (left) the mobile platform is equipped with a 360° video camera moving in the remote environment (RE), (center) the user wears a virtual reality head-mounted display (HMD) walking in the local environment (LE), and (right) the user’s view of the RE on the HMD. Different translation and rotation gains are used in this case to manipulate the mapping between user’s movement in the LE and robot’s movement in the RE, such that the user can explore REs with different sizes or heterogeneous layouts from LE using this setup.

3 IMPLEMENTATION

We implemented the prototype of a 360° video-based RDW telepresence system based on the considerations described above.

Figure 3 illustrates the 360° RDW telepresence robot in the RE. A Pioneer 3-DX mobile robot is used as the mobile base to carry the 360° camera moving through the whole RE, which works in a differential-drive way. In addition, a Ricoh THETA S 360° camera is equipped on the mobile robot for capturing a 360° live stream from the RE, which works in a 1280 × 720 resolution and a 15fps frame rate. Both the mobile robot and the 360° camera are connected with a Ubuntu laptop via USB cables. The laptop runs robot operating system (ROS) Indigo and serves as the core for robot movement control, device driving, remote communication, message publishing and subscribing. On this laptop, two nodes run under the ROS Indigo, which are responsible for controlling robot’s movement and capturing 360° live stream separately. When the setup is online, the ROS nodes publish the ROS messages about 360° live stream from the RE to the LE via network; while the mobile robot subscribes the ROS messages for movement control from the LE simultaneously, and updates its position and orientation in the RE according to the parameters inside the ROS messages.

In the LE the user is equipped with an HTC Vive HMD with the lighthouse tracking system. The HMD displays the 360° video-based RE with a resolution of 1080 × 1200 pixels per eye. The diagonal field of view is approximately 110° and the refresh rate is 90Hz. Beyond the tracking area, a pair of lighthouse tracking stations are attached to detect the update of user’s position and orientation, by which the sensor on the HMD can be tracked in real-time. The tracked data of the user’s movements in the LE is packaged in the form of ROS messages, and then transmitted to the remote side via network and used for the movements control of mobile robot in the RE. In this way, controlling a robot’s movements in the RE by means of real

walking in the LE is possible. A graphics workstation, which has a 3.5GHz Core i7 processor, 32GB of main memory, and two NVIDIA Geforce GTX 980 graphics cards, serves as the communicating and calculating core in the LE. Scene reconstruction and rendering are performed on the graphics workstation. The connection between the HMD and the graphics workstation is based on an HTC Vive 3-in-1 (HDMI, USB and Power) 5m cable, in such a way the user could move freely within the tracking space. Furthermore, the reconstruction and rendering of the RE are implemented based on a spherical space modelled in Unity3D. The live stream from the RE is rebuilt and projected as a movie texture on the inner surface of

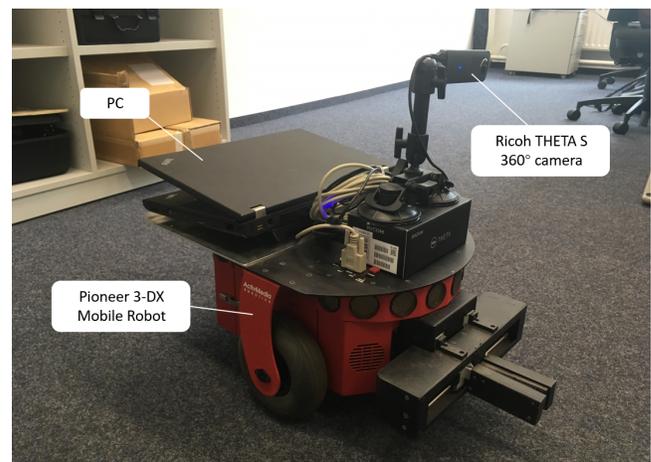


Figure 3: Prototype of a 360° RDW telepresence robot, which consists of a Ricoh THETA S 360° camera, a Pioneer 3-DX mobile robot and a Ubuntu laptop running ROS Indigo.

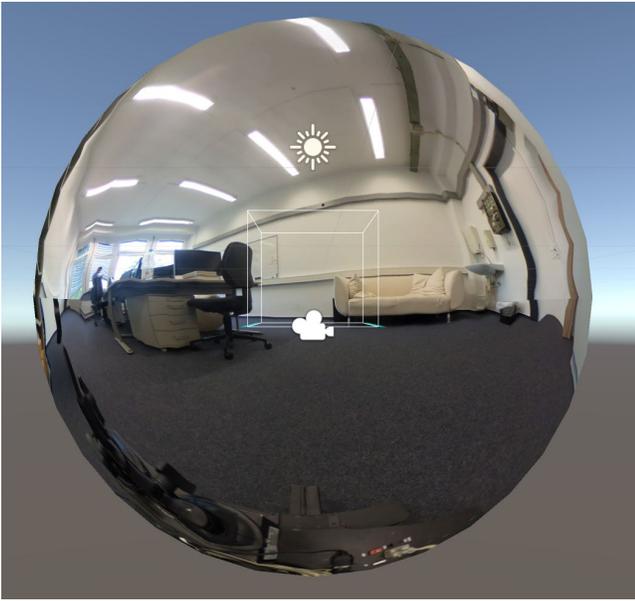


Figure 4: Reconstructed virtual scene in a spherical space, which shows the real-time RE as a rendered texture in a spherical space on the user's HMD.

this spherical space. A virtual camera is positioned in the center of this sphere to provide a perspective-correct view of 360° RE to the user from inside. Thus, users can get a 360° real-time telepresence view on the HMD using the live stream updates from the RE. The resulting reconstruction of the RE is shown in Figure 4. The communication between LE and RE is implemented via a ROS bridge between ROS and Unity3D [5].

In addition, RDW technology and different gains [17] are applied to the telepresence system to allow users exploring a much larger RE with different layouts compared to the LE (illustrated in Figure 2).

4 CONCLUSION

In this paper, we presented a 360° video-based telepresence system based on redirected walking. We described the system design and implementation of the prototype. In our prototype we used RDW techniques by means of different gains to allow the exploration of larger REs. As described above, this setup enables user to explore and interact with a much larger RE than the LE by means of real walking in the local tracked space while perceiving a 360° immersive display from the RE.

5 FUTURE WORK

In the future we would like to further reduce the current latency of movement control and image update. Hence, one of the main aspects of future work will be focussed on the improvement of the telepresence system so that it can be used in more real-time situations. In addition, we would like to explore other VR setups in the LE to display the 360° video-based RE. In particular, we have already explored CAVE-like setups (as illustrated in Fig. 5), and are interested in introducing more interactive behaviors and virtual

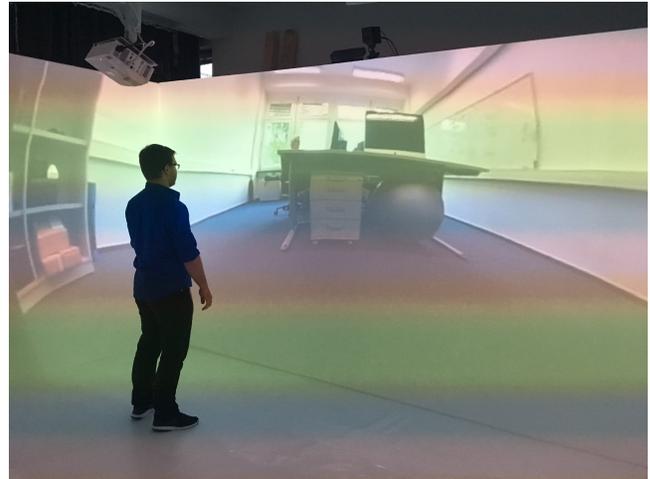


Figure 5: Application of 360° telepresence system in a CAVE-like space. In this case, the reconstructed virtual RE is rendered and projected inside a CAVE-like space by projectors.

avatars or objects into the system during the interaction with REs. Furthermore, we will test different REs and application domains like exploration of hallways, cooperation in business meeting rooms or inspections of outdoor scenarios.

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