Towards a wearable interface for immersive telepresence in robotics

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Abstract. In this paper we present an architecture for the study of telepresence, immersion and human-robot interaction. The architecture is built around a wearable interface that provides the human user with visual, audio and tactile feedback from a remote location. We have chosen to interface the system with the iCub humanoid robot, as it mimics many human sensory modalities, including vision (with gaze control) and tactile feedback, which offers a richly immersive experience for the human user. Our wearable interface allows human participants to observe and explore a remote location, while also being able to communicate verbally with others located in the remote environment. Our approach has been tested from a variety of distances, including university and business premises, and using wired, wireless and Internet based connections, using data compression to maintain the quality of the experience for the user. Initial testing has shown the wearable interface to be a robust system of immersive teleoperation, with a myriad of potential applications, particularly in social networking, gaming and entertainment.

Key words: Telepresence, immersion, wearable computing, human-robot interaction, virtual reality

1 Introduction

Recent decades have seen great advances in technology for the development of wearable devices and their application in robotics. Teleoperation, telemanipulation and telepresence are research areas that benefit from the wide repertoire of opportunities offered by sophisticated, intelligent and robust wearable devices. Researches have paid special attention on telepresence in robotics, systems that allow humans to feel physically present in a robot at remote locations [1, 2]. Sufficient, accurate, multi-modal sensory information from the remote operator and the environment are required to create a sense of presence, so that the human user feels immersed in the remote environment.

The virtual reality (VR) games industry is also a driving force behind the increased interest in telepresence, though the development of sophisticated devices for the study and implementation of telepresence. Telepresence and teleoperation are now being employed in office settings, education, aerospace, and

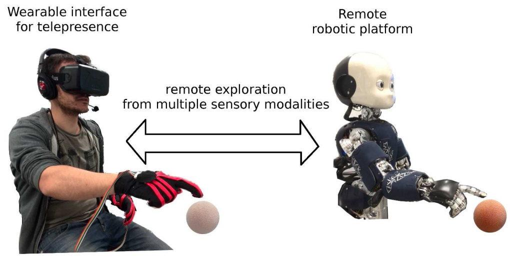


Fig. 1. Wearable interface for telepresence composed of multiple sensory modalities such as vision, touch and audio available in the iCub humanoid robot platform.

rehabilitation, as well as gaming and entertainment [3]. Space research and military markets have also seen an opportunity to influence the development of applications making use of teleoperation and telepresence [4, 5].

Despite advances in technology, robust systems that offer a natural experience of human-robot interaction are still a challenge [6]. This is due, at least in part, to the complexity of perceptive information that needs to be transferred to the user in order to create a feeling of presence, of being in a remote location [7]. The lack of multisensory feedback have been identified as major problems in the study of telepresence [8, 9]. Vision, tactile and proprioceptive information, depth perception, facial expressions and audio (including spoken language) need to be delivered to the human user with minimal delays (or 'lag') [10].

Here, we extend our previous work on telepresence [11] with the development of a wearable interface and architecture to immerse the human in a remote environment through the use of a robotic platform and multiple sensory modalities. Specifically, we have developed a wearable bi-directional interface for telepresence. The system provides visual, tactile and audio feedback to the human participant from the remote location through a humanoid robot. At the same time, the system allows for the remote control of the robot's vision, through the robot's head movements, allowing for the visual exploration of the remote environment. The user can also provide and receive audio, enabling interaction between the human user and other humans present in the remote location.

2 Methods

2.1 iCub humanoid robot

The iCub humanoid robot was chosen for integration with the telepresence system because it mirrors many human functions and sensing modalities. The iCub is an open robotic platform that resembles a four year old child. This robot, composed of a large number of articulated joints, is capable to perform complex movements, which make the iCub one of the most advanced open robotic systems, and suitable for the study of cognitive development, control and interaction with humans [12, 13]. The design of its limbs and hands allow it to perform natural, complex and dexterous movements, whilst its head and eyes are fully articulated for smooth and precise head and saccadic movements. The robotic platform also provided with multiple sensory modalities, such as vision, hearing, touch and vestibular modalities (Figure 2).

The iCub is also capable of producing facial expressions, e.g. sad, angry, happy, which are essential to natural, realistic communications with humans. These facial expressions are generated by LED arrays located on the robot's face. The type of emotion displayed can be altered depending on the feedback from both the sensing modalities and the interactions with other humans [14]. The use of a humanoid, more 'life-like', robot, it is hoped, would not only increase the levels of immersion for the remote operator, but also the receptiveness of other human engaging with the robot.

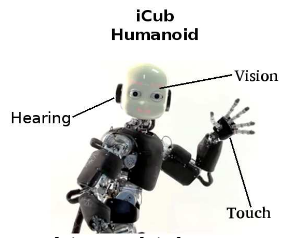


Fig. 2. iCub humanoid robot and its multiple sensory modalities used for the development of the wearable interface for telepresence.

2.2 Visual feedback

Visual feedback from the remote environment is achieved with the Oculus Rift (DK2) coupled to the eyes of the iCub. The Oculus Rift is a light-weight headset developed by Oculus VR that allows humans to be immersed in a virtual environment (Figure 3a). The headset, composed of two lenses with high resolution display each, was primarily developed for gaming and displaying other virtual environments. The dual-display feature of the Oculus Rift provides the user with the sensation of depth, through stereo-vision, and offers immersion in a 3D world, which increases the feeling of being present in the remote environment.

A multi-axis head tracking system, based on a gyroscope and an accelerometer, is integrated into the Oculus Rift, which allows the user to explore the virtual environment in a manner akin to that of exploring the real world [15]. Here, we use these features to allow the human to observe and explore the iCub's environment by remotely controlling the gaze and head movements of the robot.

2.3 Tactile feedback

The high accuracy of the iCub tactile sensory system has been demonstrated with multiple perception and exploration experiments [16, 17, 18, 19, 20]. Then, to take advantage of this rich source of information, a pair of gloves were developed to provide the human with tactile feedback from the hands of the iCub (Figure 3b) [21]. The gloves remotely connect the fingertips and palms of the user to those of the robot. Tactile feedback, based on vibrations, is proportionally controlled by applied pressure to the hands of the iCub.

The vibrations within the gloves are generated by a set of small and precise coin vibrating motors from Precision Microdrives. These motors are attached to the five fingertips and palm of each glove. A module for the activation, communication, control and synchronisation of the vibrating motors has been developed and implemented in an embedded system based on the Arduino Mega 2560 microcontroller (Figure 3b). The vibrations are generated by taking tactile pressure measurements from the capacitive sensors on the iCub's hands. The pressure measurements are encoded and controlled using a PWM (Pulse-Width Modulation) technique. Our system is capable of generating smooth and accurate vibrations, by converting the range of pressure values from the robot (0 to 255) into volts (0 to 3) that are used to drive the motors located in the tactile gloves worn by the human user.

(a) Oculus Rift (b) Tactile gloves

Fig. 3. a) Oculus Rift and b) tactile gloves coupled to the iCub's eyes and hands, for visual and tactile feedback, respectively.

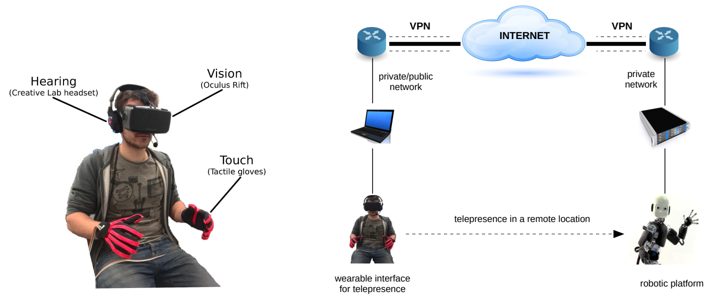
2.4 Audio feedback

Audio feedback is implemented through the integration of two omnidirectional Hama LM-09 microphones, one placed on either side of the iCub, and a Creative HS800 audio headset (headphones and microphone) from Creative Labs Inc worn by the user (Figure 4a). The dual microphones located around the robot provide a stereo sound effect, which create a more immersive experience for the user. Our module was designed with the option to enable and disable the audio feedback from the iCub, in order to test the relative importance of audio in levels of immersion.

2.5 Control architecture

The integration of the multi-sensory modalities, the bidirectional transfer of data and the need for low-latencies in transmission require a robust control architecture. We have developed an architecture that offers modularised functionality, with precise control of timings between modules for local and wide-area networks (e.g. the Internet), whether these be public or private (Figure 4b).

The architecture has two main components: the human side, which consists of the wearable interface (the Oculus Rift, gloves and headset) and the robot side (at the remote location), which is composed of the neck and eye motors, cameras, tactile sensors and microphones. The communication channel between both environments is established through Internet. The communication is maintained through a Virtual Private Network (VPN) as this offers a secure and reliable communication channel.



(a) Wearable interface (b) Architecture for telepresence

Fig. 4. Wearable interface for telepresence and immersion in robotics. The interface is composed of different subsystems that provide the human with multiple sensory inputs from a humanoid robot in a remote location.

The modules for our proposed architecture for telepresence have been developed using the C++ language and the YARP middleware (Yet Another Robot Platform), which has been designed for robust communication in robotic platforms [22]. The low level description of the modules is shown in Figure 5.

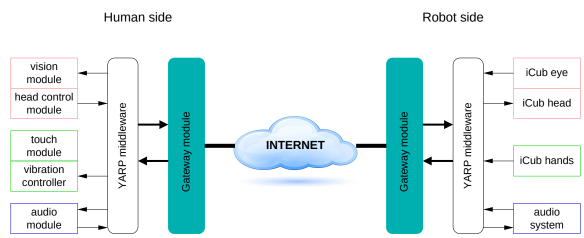


Fig. 5. Low level description of the modules that compose the proposed architecture for telepresence with the iCub humanoid robot.

The visual module uses two-way communication. An image stream is captured from each eye of the iCub and is sent to the displays of the Oculus Rift. These images need to arrive with minimal latency and optimal quality. Initially, raw image data was passed between the robot and user, however this produced very low frame rates (∼4Hz) and greatly reduced the quality of the experience. We therefore introduced Motion Joint Photographic Experts Group (MJPEG) encoding and decoding that vastly reduced the data volume and the amount of bandwidth required to send the data. This compression increases the image display frame rates (∼25Hz) and the computational overhead is now minimal. The motions and orientation of the user are recorded from the gyroscope and accelerometer of the iCub and converted into a vector stream for transmission. The head movements of the user are translated before being sent to the Cartesian gaze controller previously developed for the iCub [23]. An initial calibration is also included, to synchronise the orientation of the user with that of the robot. The vision and head control modules are precisely controlled and synchronised to achieve a smooth and natural behaviour of the iCub in the remote environment.

A touch module has been developed to read the pressure measurements from the palms and fingertips of the iCub. This module is responsible for the calibration and conversion of the data received from the robot and sending that data to the tactile gloves. A vibrating control module is interfaced with an Arduino Mega 2560 microcontroller, in order to control the vibration intensity of the motors based on a PWM technique.

An audio module has been constructed, based on the PortAudio library [24], to provide two-way communication between the user and the remote environment. For sending and receiving audio feedback, server and client modules have been developed and implemented for both user and robot.

To allow for the bi-directional transfer of information outside local area networks, e.g. through the Internet, a gateway system is required to provide a virtual bridge between distinct networks (e.g running different IP subnets); this is essential for the YARP middleware, which relies on IP based communication. By specifying IP sockets and only allowing specific data to pass, the gateway also provides added robustness to the system, and some additional security features.

3 Results

Our wearable interface and architecture for telepresence and immersion of the human with the iCub humanoid robot was tested from different physical locations. Because it is not easily portable, the iCub was always located at the Sheffield Robotics Laboratory at the University of Sheffield. However, the lightweight and compact nature of the wearable interfaced allows it to be tested from multiple remote locations. These included a location within the same building as the robot, domestic residences and public venues in the city of Sheffield, the University of Oxford and the Arts institute of London.

To provide flexibility, the telepresence modules have been developed for a wide range of computer platforms with Microsoft Windows or Linux operating systems. Our system was tested in a mobile computer with the following specifications: Core i5 Processor, 4 GB RAM, NVS 3100M NVidia Graphic processor. The iCub was controlled by a dedicated computer system with the following features: Xeon E5-1620 Processor, 16 GB RAM, Nvidia Quadro K2200 Graphic processor, 4GB RAM for CUDA. These systems provided appropriate computational power to minimise temporal delays in data processing from vision, touch and hearing sensing modalities, and control of head movements; such levels of operation are vital for creating an effective sense of presence, and levels of immersion necessary for the successful teleoperation of a robot, in any applicaiton.

The wearable interface for teleprescence allows a human user to explore visually a remote environment through the eyes of the iCub. The neck of the robot, and thus its visual field, can be controlled simply by moving the user's own head while wearing the Oculus, creating a natural, immersive experience. The human user is also able to feel remote contacts with objects, based on the controlled intensity of vibrations, through the haptic gloves. This feature also allows the human to perceive object properties, such as texture, shape and roughness. It is already known that adding multiple sensory inputs has a greater effect in creating feelings of presence and immersion than focussing on improving a single sensation; for example, adding accurate auditory and tactile feedback is more effective than increasing the photorealism of the visual feedback alone in creating a heightened sense of immersion [25, 26]. Combining tactile, auditory and visual feedback tremendously improves the experience of immersion with the iCub at a remote environment. The auditory system, furthermore, permits effective verbal communication between the user and those present in the remote environment.

For the current study, the delays in receiving tactile and audio feedback, and between natural movements of the human head and the response of the iCub, are imperceptible for the user. These results show that our wearable interface offers a robust and suitable system for immersion, and an effective experience for the teleoperation of robotics.

4 Conclusion and future work

In this work we presented a wearable interface and architecture for the study of telepresence and immersion in robotics. Our system is composed of different modules able to receive inputs from multiple sensory modalities, including vision, touch and hearing, and can transmit information such as audio and head orientation. These features allow human users to experience a more natural teleoperation of a robot in a remote environment. In the future we plan to enhance the experience by including a system to track the user's limbs, making it possible to manipulate objects in the remote environment. This will make the teleoperation of robots much more effective in, for example, cleaning dangerous wastes or exploring inhospitable environments. In addition, we will also track the user's facial expressions and reflect these in the robot, allowing for more realistic, natural communication between users and those in the remote environment. This will greatly enhance the possibilities for the teleoperation of robots in social applications, such as teleconferencing, gaming and entertainment.

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