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Multisensory wearable interface for immersion and telepresence in robotics

Uriel Martinez-Hernandez, Luke W. Boorman, Tony J. Prescott

***Abstract*—The idea of being present in a remote location has inspired researchers to develop robotic devices that make humans to experience the feeling of telepresence. These devices need of multiple sensory feedback to provide a more realistic telepresence experience. In this work, we develop a wearable interface for immersion and telepresence that provides to human with the capability of both to receive multisensory feedback from vision, touch and audio and to remotely control a robot platform. Multimodal feedback from a remote environment is based on the integration of sensor technologies coupled to the sensory system of the robot platform. Remote control of the robot is achieved by a modularised architecture, which allows to visually explore the remote environment. We validated our work with multiple experiments where participants, located at different venues, were able to successfully control the robot platform while visually exploring, touching and listening a remote environment. In our experiments we used two different robotic platforms: the iCub humanoid robot and the Pioneer LX mobile robot. These experiments show that our wearable interface is comfortable, easy to use and adaptable to different robotic platforms. Furthermore, we observed that our approach allows humans to experience a vivid feeling of being present in a remote environment.**

***Index Terms*—Telepresence, immersion, remote exploration, wearable computing, human-robot interaction.**

I. Introduction

TELEPRESENCE deals with the idea or sensation of being present in another environment by means of a communication medium, allowing humans to see, explore and feel what is happening [1]. This idea of remote presence and control has an enormous field of applications. Nowadays, telepresence is being employed in office settings, education, rehabilitation, gaming and entertainment [2]. It has also played an important role in space research, military markets, manufacturing, assembly and training of personnel [3]. Thus, telepresence offers a vivid experience for social interaction with others. However, the feeling of telepresence requires sensory feedback from multiple modalities, which is also essential to permit humans to interact and perform their jobs safely and pleasantly with the remote environment. To convey the idea of remote presence, control and immersion, it is also necessary a robotic platform capable to provide sensory feedback from multiple modalities, e.g., vision and touch, and imperceptible time delay [4], [5].

In this work, we have developed a multisensory wearable interface for immersion and telepresence with the iCub humanoid robot. Our interface is composed of multiple sensor inputs, e.g., vision, touch and audio, that coupled to the iCub eyes, hands and ears provide to the human multimodal feedback. A telepresence system needs to provide sensory feedback to the operator, but also to allow to control the robot to explore and interact with the remote environment. For that reason, we have implemented a modular architecture for remote control of the head and eyes movements of the humanoid through the output signals from our wearable interface. We have integrated the capability to communicate and control the robotic platform across different Internet Protocol (IP) subnets, together with a secure and reliable communication channel using Virtual Private Networks (VPNs). Furthermore, the use of a modular design with a state of the art middleware library, allows to easily interface our wearable device with different robotic platforms. All these functionalities make our multisensory wearable interface easy to use, scalable and multiplatform, which offer to the human a more vivid feeling and enhanced experience of being present in a remote environment.

We validate our work with experiments where humans, employing our wearable interface, are able to control the iCub humanoid while exploring and interacting with humans and objects in the remote environment. The reliability of communication of our wearable interface has been tested by controlling the humanoid robot from multiple locations. Thus, humans are able to immerse and feel present, in the same room where the humanoid is located, through feedback from multiple sensor inputs. Finally, we have tested the capability of our interface to work with different robot platforms, connecting it to the Pioneer LX mobile robot to control its movements while exploring a remote location.

Overall, the functionalities offered by our wearable interface and its capability to provide multimodal sensory feedback to humans, make it suitable for immersion and telepresence in robotics to interact with humans and the environment.

The rest of this work is organised as follows. In Section II we describe related studies to our work. The robotic platform used for immersion is described in Section III-A. The wearable devices used for multisensory feedback are described in Section III-B. In Section III-C the architecture for robot control and sensor feedback are presented. The results and discussion from our experiments are described in Section IV. Finally, the conclusion of our work is shown in Section V.

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II. Related work

In the early 1950s the first approach for remote control, composed of electrical servomechanisms and closed circuit television (CCTV), allowed humans to operate a remote robotic device [6]. A decade later, in the 1960s, integration of force sensors and Head Mounted Displays (HMD), allowed users to both remotely control the arms of a robot and observe the result of their arm movements [7]. Since then, more complex telepresence systems have been designed for controlling dexterous robotic platforms. Robot arms for space applications were controlled adjusting the level of immersion and telepresence selected by the user [8]. Remote control of a robot, equipped with an arm and two CCD cameras, was achieved using a visual display attached to a helmet and joystick [9], [10]. Traditionally, telepresence systems have been composed of arm manipulators and visual feedback, which have shown interesting progresses [11], [12]. However, integration of multimodal feedback, e.g., tactile and audio, can provide enhanced and sophisticated systems that benefit from multimodal data in the environment [13], [14]. The first man-machine interface, equipped with multiple sensor feedback (CCD cameras, integrated microphones and pressure sensors) was developed for control of a dual-arm robot [15].

Robust, lightweight and multimodal wearable devices have shown their potential for the development of sophisticated and intelligent robotic applications [16], [17]. These multimodal systems can create the sensation of full immersion that provide users with the three major sensory inputs of visual, auditory and haptic information [18], [19]. Specifically, teleoperation, telemanipulation and telepresence have been benefited from these wearable devices that, coupled to robots composed of wheels, a stand and a camera, provide humans with an enhanced control of a robot located in a remote environment [20], [21]. The improvement of immersion and telepresence experience have also been possible by the rapid progress achieved in robot and sensor technology [22], [23], [24]. Particularly, humanoid robots, which try to mimic the human body structure, movements and sensory capabilities, offer a more natural platform for remote control, exploration and interaction with humans and the surrounding environment [25], [26], [27]. Some works have shown that robot platforms that include a degree of anthropomorphic form and function, make users feel a stronger presence in a remote environment, but also provide powerful physical and social features to engage humans in interaction [28], [29]. Teleoperated humanoids, designed for the study of human-robot interaction, showed that humans not only easily engage in interaction but also tend to create an identity of the robot [30], [31]. However, these works did not provide a wearable and immersive device for the operator, decreasing the feeling of telepresence. Despite the effort to develop wearable and immersive devices to provide multimodal feedback from humanoids, e.g., vision, touch, audio, depth perception and facial expressions that contribute to create a feeling of remote presence, they remain as a challenge for telepresence systems [32].

This has motivated our study on wearable interfaces for telepresence that are multiplatform, lightweight and capable to provide sensory feedback in multiple formats. In next sections we present our wearable device that integrates multimodal inputs from a humanoid for immersion and telepresence. Our wearable device has the potential to simultaneously provide vision, touch and audio feedback to the human from the remote environment. These features, together with the capability to control the robot head for exploration of the environment, allow the user to immerse and feel an enhanced experience of being present in a remote location.

III. Methods

A. *Immersive robotic platform*

Telepresence has been studied using different robot platforms, where most of them are mobile robots generally composed of wheels, a pedestal and a screen, e.g., Anybot QB, mObi, MeBot [33], [34]. Despite these robots have features needed for telepresence (e.g., video, audio, sensor feedback), they do not incorporate any human morphology. Physical embodiment is important to provide a better immersion and telepresence experience for both, the human operator and the human interacting with the robot [35]. Table I shows the characteristics of different robotic platforms for telepresence.

In this work, we use the iCub humanoid for immersion and telepresence given the features in Table I. This robot has a biomimetic design that mirrors many human functions and sensing modalities. The iCub is an open platform inspired by the human morphology that, composed of 53 degrees of freedom, is able to perform complex and dexterous movements. These characteristics make the iCub one of the most advanced open robotic systems suitable for the study of cognitive development, telepresence and human-robot interaction [36].

The biomimetic design of its arms and hands allow to execute natural and dexterous movements. Its head and eyes are fully articulated for smooth and precise head and saccadic movements. The iCub is integrated with vision, touch and hearing sensing modalities, that together with computational models, allow it to interact, explore and perceive its surrounding environment as humans do [37], [38]. Figure 1 shows the iCub and its sensory modalities. This robot is also capable to

Robot	vision	touch	audio	mobility	head	arms	hands
MeBot	1 camera	–	1 microphone	wheels	animated screen	2 arms	–
Anybot QB	1 camera	–	3 microphones	wheels	animated screen	–	–
VGo	1 camera	–	4 microphones	wheels	animated screen	–	–
iCub	2 cameras	torso, arms, fingers	2 microphones	–	bio-inspired design	2 arms	5 fingers
Baxter	1 camera	–	–	–	animated screen	2 arms	2 grippers
Nao	2 cameras	fingers	4 microphones	legs	bio-inspired design	2 arms	3 fingers

TABLE I
Characteristics available in robot platforms for telepresence

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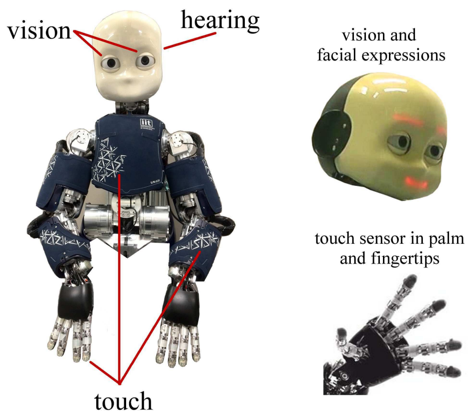

Fig. 1. iCub humanoid robot integrated with vision, hearing and touch sensing modalities, and LEDs for generation of facial expressions.

display facial expressions, e.g. sad, angry and happy, which are essential to achieve a more natural interaction with humans. These facial expressions are generated by Light-Emitting Diodes (LEDs) arrays located in the eyebrows and mouth of the robot (Figure 1). Facial expressions also are useful to identify the emotional state of the robot, which can be altered based on the multisensory feedback from the interaction with humans [39]. All these capabilities integrated in the iCub humanoid make it a more 'life-like' robot platform, that allow humans to not only increase their levels of immersion and telepresence, but also to create a more vivid experience during the interaction with other humans through the robot.

B. Multisensory wearable interface

We propose a wearable interface, composed of vision, touch and hearing sensing modalities, with both the construction and integration of state of the art devices. The modules of our interface are described in the following sections.

1) Vision: Visual feedback is provided to the human through the Oculus Rift (DK2) coupled to both eyes of the iCub humanoid (Figure 2). The Oculus Rift, a cutting-edge technology developed by Oculus VR, is a lightweight HMD that we use to give humans a visual immersion of a remote environment. This device is composed of two lenses with high resolution that provide the user with the sensation of depth, through a stereo-vision, offering a 3D immersion that enhances the feeling of being present in a remote environment.

The visual module receives two image streams from the iCub eyes, which are sent to both displays of the Oculus Rift. To provide vivid visual feedback from the remote environment, the received images need to arrive with minimal latency and high quality. For that reason, we include the Motion Joint Photographic Experts Group (MJPEG) encoding and decoding module, which greatly reduced the data volume and the bandwidth required for transmission of the image streams. This encoding method provides image display frame rates of $\sim$25 Hz with a minimal computational overhead.

The Oculus Rift is integrated with a multi-axis head tracking system, where data from $roll$, $pitch$ and yaw axes are sensed from the human wearing the MHD to remotely control the iCub head movements. This process permits the human to sense and explore the remote environment in a manner akin to exploring a local environment [40]. The data from human head movements are coupled to $roll$, $pitch$ and yaw axes of the robot using the Cartesian gaze controller previously developed for the iCub [41]. Thus, the Oculus Rift, together with visual and head movement modules, establishes a bidirectional communication that allows humans to not only see through the eyes of the robot, but also to control robot head moments for visual exploration of the remote environment. For control of robot movement a proportional controller is implemented in the control of movement module, which receives as input the error from the human head movements (target) and the current location of the robot head provided by the Cartesian gaze module. The control of movement module is also able to perform an initial calibration, recording the range of motion of the iCub head. This is used to block the information from head movements that could damage the robot, e.g., movements out of the limits of the robot neck. Figure 2 shows the functional diagram for visual feedback in our wearable interface.

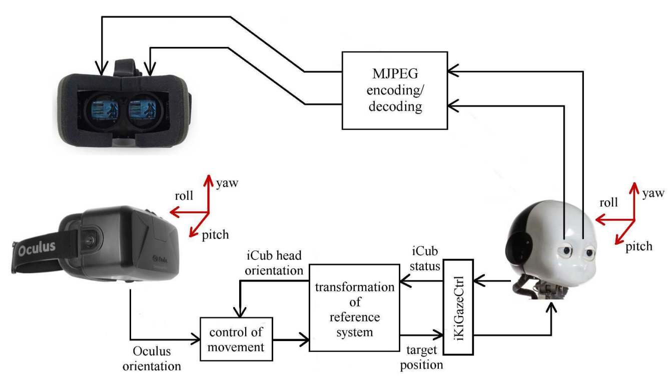

Fig. 2. Vision modality. The eyes of the iCub humanoid robot are coupled to both cameras in the Oculus Rift, which allow the human to observe what the robot sees. Control of the iCub neck permits to visually explore the remote environment where the humanoid robot is located. Coordinated frame from the Oculus Rift and the iCub are coupled with the Cartesian gaze module. The control of movement module uses a proportional controller to adjust the error from human head movements and the current location of the robot head.

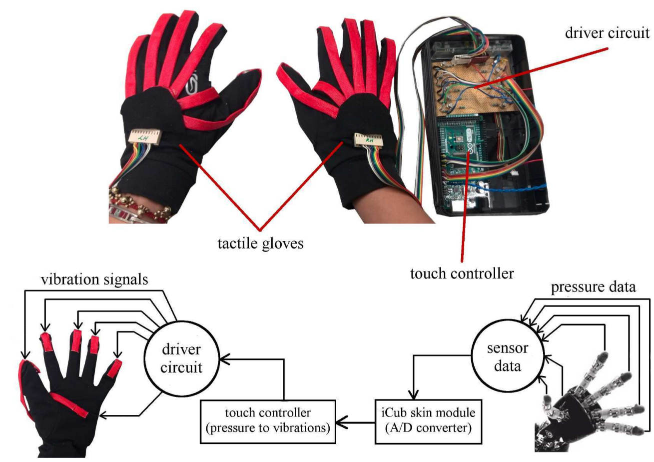

Fig. 3. Touch modality. The tactile feedback from the fingertips and palms of the iCub humanoid robot is sent to the human through the tactile gloves. This wearable device is composed of six vibrating motors for each hand, which are precisely controlled by an Arduino board.

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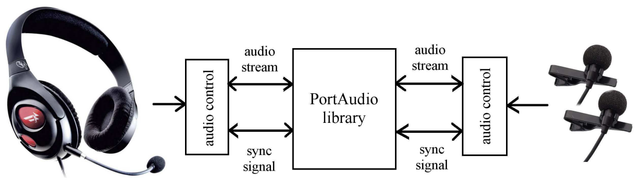

Fig. 4. Hearing modality. Communication channel that allows to sent audio feedback from a remote location to the human using the wearable interface.

2) Touch: Tactile sensing is a rich source of information that normally is underrated. However, touch allows to build a physical representation of the world and directly interact with objects [42], [43]. For that reason, we have developed a pair of tactile gloves to provide the human with feedback from the iCub fingertips and palms (Figure 3). The iCub is equipped with one of the most advanced touch sensors, which have demonstrated to be robust and accurate for tactile perception, exploration and recognition [44], [45]. In this initial work, our gloves allow the human to physically feel only the hardness of an object or contact based on vibrations mapped to the pressure applied to the hands of the iCub humanoid robot.

Our tactile gloves are built with miniature and precise coin vibrating motors, from Precision Microdrives, that attached to the five fingertips and palms provide precise and controlled vibrations. We have developed modules for communication, synchronisation and control of these motors, implemented in an embedded system with the Arduino Mega 250 microcontroller. The control of the motors is with a Pulse-Width Modulation (PWM) technique, according to pressure measurements from the iCub hands. Our tactile gloves generate smooth and accurate vibrations, by encoding the range of pressure values from the robot (0 to 255) into volts (0 to 3). Thus, the telepresence experienced by humans is enhanced by physically touching objects located in the remote location. A functional diagram for touch feedback is shown in Figure 3.

3) Hearing: For hearing feedback, initially we used the microphones located in the head of the iCub. However, the high levels of noise captured by these microphones made them impractical for audio feedback. For that reason, we implemented hearing feedback with two omnidirectional microphones LM-09 model from Hama Inc. These microphones, placed on both sides of the robot, permit to detect sounds with stereo effect from the surrounding environment of the robot. The sound is received by the human using a Creative HS800 audio headset composed of headphones and microphone.

The module to control the hearing feedback has been constructed using the open source PortAudio library [46], to set a two-way audio communication channel between the human and the robot. To send and receive audio, server and client modules have been developed for both the human and robot environments. This could also permit the user to be aware and react, by controlling the robot head movements, to different sounds captured by the remote microphones. Figure 4 shows the functional diagram for hearing feedback. The complete multisensory wearable interface is shown in Figure 5, which allows humans to immerse in a robot platform to explore, interact and feel present in a remote environment.

C. Control architecture

We have developed a control architecture that integrates the multiple sensing modalities of our wearable interface for immersion and telepresence. This architecture offers a modularised functionality that can be implemented for robot control in local and wide area networks, e.g., the Internet, whether these are public or private (Figure 6).

The control architecture of our wearable interface is composed of two main components; the human and robot environments. The human environment includes the Oculus Rift, tactile gloves and a headset, which provide vision, touch and hearing sensing. The data from these sensing modalities are provided by the eyes, tactile sensors and microphones from the iCub humanoid placed in the robot environment. Our control architecture, with a frequency loop of 1 kHz, synchronises the modules for vision and touch which work at 25 Hz and 50 Hz. Here, we use the PortAudio library for control of audio feedback using built-in methods. Synchronisation of modules and multi-platform features are implemented with the ‘Yet Another Robot Platform’ (YARP) middleware. This middleware allows robust communication of software and hardware modules, providing a transparent framework for development of robotic application across multi-platform systems [47]. Both the human and robot environments communicate through Internet with a Virtual Private Network (VPN), which offers a secure and reliable communication channel. Bi-directional transfer of data in both, local and wide area networks is possible with the integration of gateway modules. These modules, based on the establishment of a Virtual Private Network (VPN), that offers a secure and reliable communication channel, allows to communicate networks running different Internet Protocols (IP) subnets. Furthermore, the gateway modules provide robustness and additional security features, by the specification of IP sockets and transferring of specific data.

The modules developed for our multisensory wearable interface for immersion and telepresence are open source and they are available in Github - SheffTelepresence (https://github.com/urielmtz/SheffTelepresence).

IV. Results and discussion

The modules that compose our multisensory wearable interface were developed for Linux and Microsoft Windows operating systems. Their implementation based on the modularised architecture shown in Figure 6 makes our interface adaptable and scalable. On the human side of our control architecture, the modules were developed in a mobile computer with the following characteristics: Core i5 Processor, 4 GB RAM and NVS 3100M NVidia Graphic Processor. On the robot side, we used a dedicated computer system with the following features: Xeon E5-1620 Processor, 16 GB RAM, NVidia Quadro K2200 Graphic Processor and 4 GB RAM for CUDA. These systems provided the appropriate computational power to minimise the delays from vision, touch and hearing data processing, and obtain a smooth control of head movements of the iCub humanoid robot. Low temporal delay and smooth control are desirable features to achieve an effective feeling of immersion and presence in a remote environment through a robotic platform.

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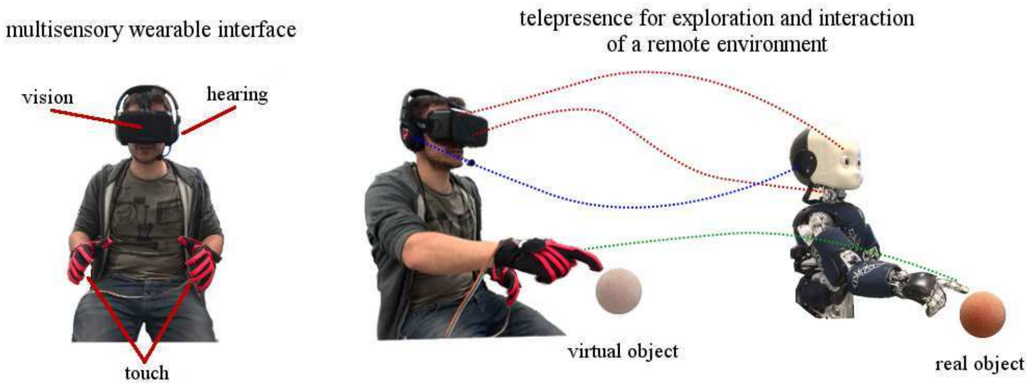

Fig. 5. Multisensory wearable interface that offers vision, touch and hearing feedback. We connected our interface to the multiple sensing modalities available in the iCub humanoid robot. Providing the human with sensor feedback in multiple formats, allows them to feel immersed in a remote environment while exploring it through touch, hearing and remote control of head movements of the robotic platform.

Our wearable interface was tested with experiments where the human and the iCub humanoid were located in different environments. The robot was located in the Sheffield Robotics Lab, while our lightweight and portable interface was worn by participants for robot control from different locations. These locations included; the same building where the robot was located, domestic residences and public venues in Sheffield, the University of Oxford and the Arts Institute of London.

Figure 7 shows multiple human participants wearing our interface for immersion and telepresence with the iCub humanoid. The participant in Figures 7(a-b) was able to see the environment through the eyes of the iCub humanoid. Also, this participant visually explored its surrounding environment by controlling the head movements of the robot platform. Vision and touch sensing modalities were employed together for telepresence by the participant in Figures 7(c-d). This participant not only observed and visually explored the world through the eyes of the iCub humanoid, but also he was able to feel a physical contact with the environment. This sensation is possible through the tactile gloves that provide vibration intensities, on the fingertips and palms of the human, mapped to pressure measurements from the contact applied on the robot hands. This experiment was repeated, but this time the participant was looking towards the robot, which allowed him to observe himself through the eyes of the robot. The participant reported to feel a strange sensation while observing his own body and movements through the iCub humanoid (Figure 7d). Interestingly, the participant tried to touch his own hand, which provided him a more realistic feeling of being immersed in the robot. In general, participants mentioned that after some minutes of wearing the interface, they found it comfortable and easy to use for control of the robot. They also mentioned to have a feeling of being inside another place visually and physically exploring it.

Another participant wearing our interface was located besides the robot (see Figures 7(e-h)). This participant visually explored the environment while controlling the head of the iCub robot based on the information from the Oculus Rift. The participant was also able to identify the robot arms when he was looking down. However, after some minutes of visual exploration, he had a feeling of being connected to that robotic arms. Furthermore, we observed that the participant felt and reacted to the physical contact provided through the tactile gloves. In Figures 7(f-h) we observe the participant looking at the robot hands towards the location where he feels the tactile contact. From this experiment, the participant reported that simultaneously receiving touch feedback and observing the robot arms enhanced his feeling of interaction with the remote environment. Even though in this work we only provide contact and hardness feedback, the results suggest

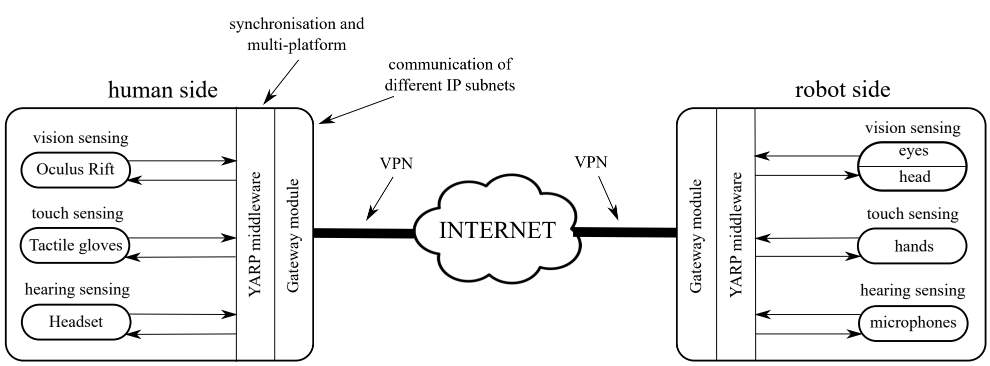

Fig. 6. Control architecture. Modularised architecture composed of human and robot side components that implement our multisensory wearable interface for telepresence. Our approach allows the connection of our interface to vision, touch and hearing sensing modalities available in different robotic platforms. This control architecture also allows to safely and reliably communicate and control the robotic platform from different IP subnets through Internet.

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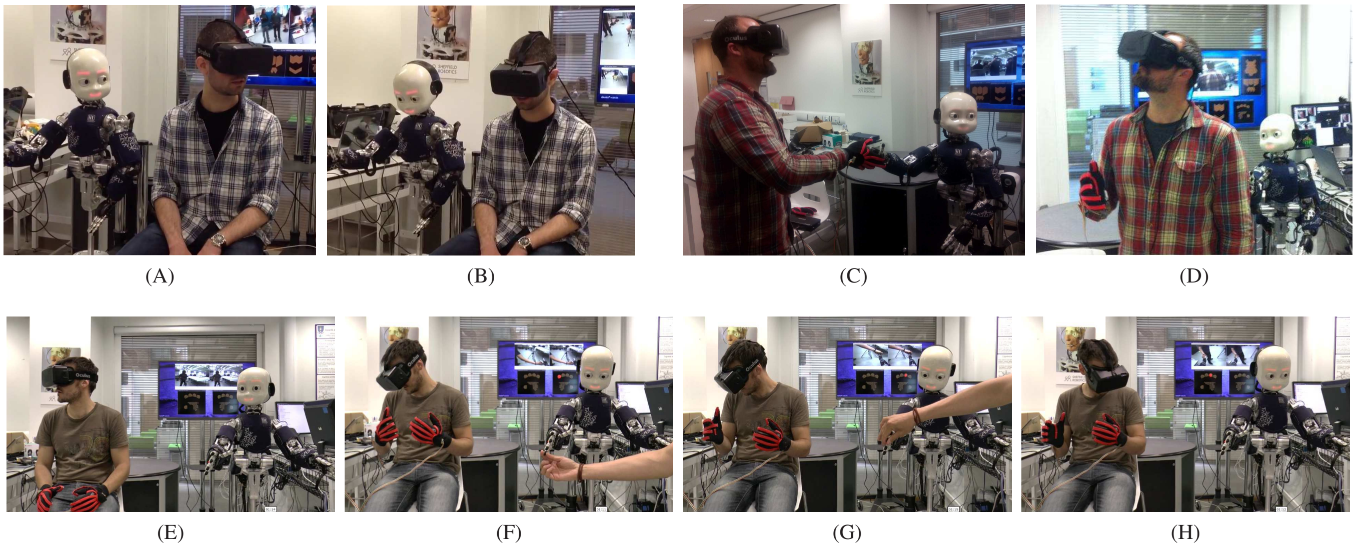

Fig. 7. Experiments for immersion and telepresence with our multisensory wearable interface. (a,b) Participant seeing the environment through the eyes of the iCub humanoid while controlling its head movements. (c,d) Participant testing both vision and touch sensing modalities, while observing his own body and movements. He also was able to touch his hand through the interaction with the robot. (e-h) In the last experiment with the robot, the participant was able to visually explore the environment and the robot body. Furthermore, he was able to feel the tactile feedback and look in the direction where the contact was applied through the hands of the robot.

that touch plays a key role for improvement of the immersion and telepresence experience. Therefore, we plan to continue developing our tactile gloves including more sensors to capture more characteristics from remote touch, e.g., texture and temperature. We repeated the previous experiments including feedback from hearing sensing, however, participants did not report any difference or improvement in the immersive experience. It seems that the quality of the audio feedback was not good enough to provide a realistic hearing immersion experience, which we believe is related to the noise from the environment and the high levels of noise from the iCub head. This suggests that we need to improve the audio feedback by adding modules responsible for data preprocessing, e.g., filtering methods and noise cancellation.

The telepresence experiment, previously describe in Figure 7, was performed by 12 participants to test and evaluate our multisensory wearable interface. Participants were asked to rank from 1 (low) to 5 (high) its comfortability, ease of use, imperceptibility (feedback delay) and contribution of each sensing modality to enhance the telepresence experience (see Figure 8). All participants performed the experiments successfully, finding our wearable interface comfortable and easy to use for immersion and telepresence. We observed that participants using both vision and touch feedback were more engaged and motivated to explore and feel the remote environment. In contrast, hearing feedback did not present a significant improvement in the experiments, and we argue that this is related to the levels of noise produced by motors and fans from the iCub head and neck. Nevertheless, these

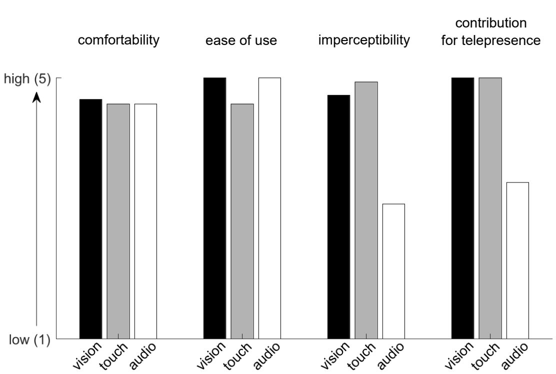

Fig. 8. Evaluation of our multisensory wearable interface for telepresence by 12 participants. We asked participants to rank from 1 (low) to 5 (high) different aspects of our interface: 1) comfortability, 2) ease of use, 3) imperceptibility (delay in sensor feedback from the remote environment) and 4) level of contribution of each sensing modality for the telepresence experience. We observe that our wearable interface is comfortable and ease to use. Vision and touch provided very low feedback delay and high contribution for telepresence. In contrast, audio feedback delay was larger and it did not significantly contribute to enhance the telepresence experience.

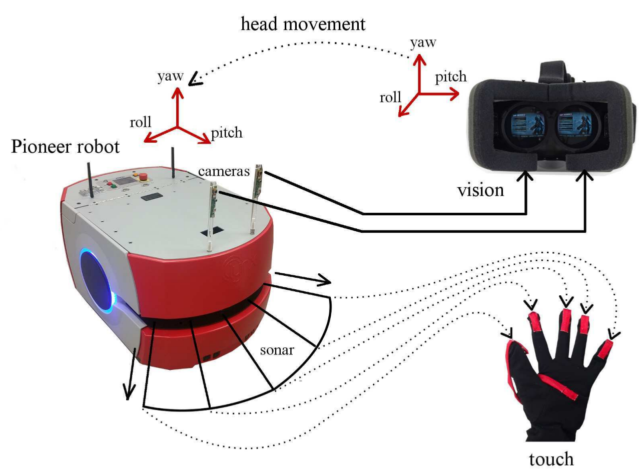

Fig. 9. Mobile robot Pioneer LX used to test the capability of our wearable interface to communicate and control different robotic platforms. Vision was connected to two cameras mounted on the top of the mobile robot. Touch was connected to the integrated front sonar. The human was able to explore a remote environment by receiving multisensory feedback, and controlling the robot movements in various directions, e.g., forward, backward, left and right.

results also contribute to identify crucial aspects of sensors and wearable devices for telepresence: 1) lightweight, comfortable and ease to use, 2) minimal latency for high imperceptibility, 2) accurate filtering for noise reduction, 3) synchronised sensor feedback for robot control, 4) adaptable and robust coupling with available sensors in robot platforms, 5) multisensory integration and feedback to enhance the perception and interaction with the environment.

The modularity and platform independent features of our control architecture allow our wearable interface to easily connect to different robotic platforms. For testing this capability, we connected our wearable interface with the Pioneer LX robot, which is an advanced mobile research platform integrated with front and rear sonars, speakers among other features (see Figure 9). For visual feedback, we added two cameras on the top of the Pioneer robot, which were connected to the Oculus Rift. For touch feedback, we connected the front sonar to the tactile gloves. In this case, given the limited number of ports available in the robotic platform, we did not add a set of microphones to provide hearing feedback to the human. The interface was tested multiple times by a volunteer with a disability that allow him to move only his head. This participant was able to see, touch and explore the environment by controlling the movement of the robot to a desired location. The Oculus Rift, connected to both cameras on the robot, allowed the participant to visually explore the remote environment while moving the robot forward, backward, left and right. He also felt, based on vibrations on his hands, the proximity and contact with objects located in the environment. After various repetitions of the experiment, the participant reported that he found our wearable interface very comfortable and easy to control, allowing him to feel virtually present in a remote location. This participant suggested to add a visual feedback from the rear of the Pioneer robot, which would permit to have a broader visual scene and be aware of what is behind of the robot while controlling its movements.

Telepresence and immersion in robotics required data in multiple formats from the surrounding environment. Nowadays, state of the art sensors provide humans with rich information to enhance perception and control while being immersed in a robot platform. However, the integration of multimodal sensors and their contribution to the feeling of being present in a remote environment remain under investigation. For that reason, in this study we performed various experiments that show how the application of synchronised and controlled multimodal sensors, into wearable devices coupled with robotic platforms, plays a key role to provide humans with an enhanced feeling of telepresence. Wearable interfaces, like the one proposed in this work, can be used for applications such as remote teaching, social interaction, monitoring, among others. However, applications such as surgery that require dexterous, delicate and highly precise movements, also need of the design of highly accurate controllers which is out of the scope of this study. Overall, results from the experiments demonstrate that our multisensory wearable interface is suitable for immersion and telepresence with robotic platforms, providing a vivid exploration and interaction experience with humans and objects in a remote environment.

V. Conclusion

In this work we presented a wearable interface composed of multiple sensory modalities for immersion and telepresence in robotics. Our wearable interface is integrated by vision, touch and hearing sensing input for interaction with humans and objects in a remote environment. For vision and hearing sensing we use the Oculus Rift and a headset from Creative Labs. For touch sensing we developed a set of tactile gloves to provide vibrations from the physical contact performed in a remote environment. Integration of these technologies, together with control modules, allowed to develop an interface that permits humans to immerse and control a humanoid robot platform, to experience vision, hearing and touch sensing from a remote location. Overall, our wearable interface tested with multiple experiments and robotic platforms, demonstrated to be comfortable, adaptable and easy to use to provide a vivid sensation of immersion and telepresence with robots.

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