Immersive ROS-integrated framework for robot teleoperation

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ABSTRACT

The development of natural interfaces for human-robot interaction provides the user an intuitive way to control and guide robots. In this paper, we propose a novel ROS (Robot Operating System)-integrated interface for remote control that allows the user to teleoperate the robot using his hands motion. The user can adjust online the autonomy of the robot between two levels: direct control and waypoint following. The hand tracking and gestures recognition capabilities of the Leap Motion device are exploited to generate the control commands. The user receives a real-time 3D augmented visual feedback using a Kinect sensor and a HMD. To assess the practicability of the system experimental results are presented using as a benchmark the remote control of a Kuka Youbot.

Keywords: 3D Interaction, gesture, augmented reality.

Index Terms: I.2.9 [Artificial Intelligence]: Robotics—Operator Interfaces; H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, Augmented and Virtual Realities

1 INTRODUCTION

Thanks to the advancements in the robotics research field, robots are now able to execute more and more demanding tasks in an autonomous way, assisting humans in everyday tasks. Despite the significant progress, the execution of complex tasks is still a challenge, due to the complexity and to the variability of the environment in which the robot acts. Human cognitive abilities can be exploited to tackle difficult scenarios. Involving a human operator in the loop has been proved to be a viable solution to accelerate the development of assistance robots [6]. The classical way to combine the robot skills with the user's capabilities is through teleoperation [9]. Historically three models have been identified for teleoperation control strategies. **Direct control**, where the user directly controls the robot movements, **shared control**, where the control of the task aspects is shared and **supervisory control**, where a user gives commands to a robot, which executes them autonomously. Direct teleoperation has been proved to be the most effective approach, but its performance drops when some time delay (communication latencies or operator neglect) is introduced in the loop. On the other hand fully autonomous behaviors are less effective, but do not suffer from time delay sensitivity. Between the two extremes, the concept of adjustable autonomy has been introduced [3]. In this approach different levels of autonomy are considered, changing the degree of the robot self-control during the task execution. Several interaction paradigms have been explored, such as graphical user interfaces (GUI), gesture recognition, natural language-based interfaces, virtual reality interactions. Considering GUI-based approaches [6, 8] the user is presented with an interface through which he interacts with the robot end effector pose to control the robot movements or to define goals. From these works the efficiency gained from the use of autonomous skills over the direct control approach emerges clearly. When we consider manipulation tasks, it has been shown that gestures and in general body based methods, improve the user dexterity to perform the task [1]. Several gestural interfaces have been presented to specify high-level goals for the robot [7, 5]. In the context of adjustable autonomy for manipulation tasks, we strongly believe in the possibility to achieve a better human-robot interaction, increasing the ownership illusion towards the remote robot body. With this approach user's autonomic responses (like collisions avoidance) take also place during the task execution [1]. Moving from this assumption we present a ROS-integrated teleoperation framework. Hand gestures are used to control every aspect of the task and of the human-robot interaction. The system exploits the hand tracking features of the Leap Motion device [4] to provide the user with two different autonomy levels selectable online during the task execution. The user can choose between direct control and shared control. In the latter waypoints are defined with hand gestures and the robot moves autonomously through them. To achieve a high degree of user's embodiment in the robot body, we investigate the use of an augmented 3D feedback through an Head Mounted Display (HMD). An explorable mesh is generated from a Kinect RGBD camera capturing the remote environment in which the robot is acting. The mesh is augmented with 3D information about the waypoints selected and the user's hand position and fed back to the user.

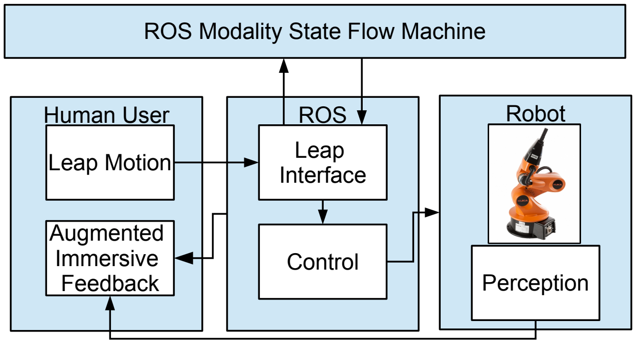

Figure 1: The system architecture. The ROS Leap Interface exposes data from the Leap Motion device in ROS. The information about hands reference frames, gestures and closures are used by ROS both to switch control mode (by the Modality State Flow Machine) and to control the robot in both the modes (by the ROS Control Node). The perceptual stream from the remote robot side is sent back to the user's side for the augmented immersive feedback. The feedback is augmented with information about hands positions and waypoints coming from the ROS control node and the ROS Leap Interface.

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2 METHODS

The system architecture is represented in Figure 1. User's hands motions are captured with the Leap Motion device. Hands reference frames, closures and gestures are exposed in ROS by the Leap ROS Interface. Gestures are used both by the ROS Modality State Flow Machine to choose the control modality and by the ROS control node accordingly to the control chosen modality. The environment on the robot side is captured and the perceptual stream is sent back to the user's side to generate the immersive feedback augmented with information about hands positions (from the ROS Leap Interface), and the saved waypoints (from the ROS control node).

2.1 ROS Nodes

The hands gestures exposed by the Leap ROS Interface are used to select online between two different control modalities: direct control of the robot end effector and grip closure and shared control. In the first mode a position control is implemented using the human right hand pose as a reference, while in the latter the user can freely move his right hand and define waypoints for the robot arm using the Keytap gesture. Once all the waypoints are defined the Moveit! grasp planning node [2] plans and executes a trajectory for the robot arm. The user is also able to explore the visual feedback scene with left hand movements. The scene view point is moved according to left hand position, pitch and yaw and it can be reset with an anti-clockwise Circle gesture of the left hand. A left hand Swipe gesture is used to switch between modalities.

2.2 Augmented 3D feedback

The Augmented Reality application has been developed using a newly created framework for high-performance AR, called Compact Components (CoCo), composed of a core library and of several components. The first components receives the video and depth streaming from the computer running the Kinect and decompresses them. The Kinect RGB channel is streamed using h264 compression (435kbps in average) and the depth with zn16 compression from OpenNI2 (21Mbps in average). The decompressed buffers are then passed to another component which uses them to construct a point cloud with added interpolated points to increase the quality of the mesh. The point cloud is then passed to the component in charge of managing the graphics which will render the augmented scene. The virtual objects are displayed according to the information received through an UDP connection from the robot side. The visualized scene is updated at the same frequency of the Kinect (30 Hz), while the added virtual objects are rendered at 60 Hz to improve the visual feedback to the user.

Figure 2 shows the user setup together with the virtual and remote scenes.

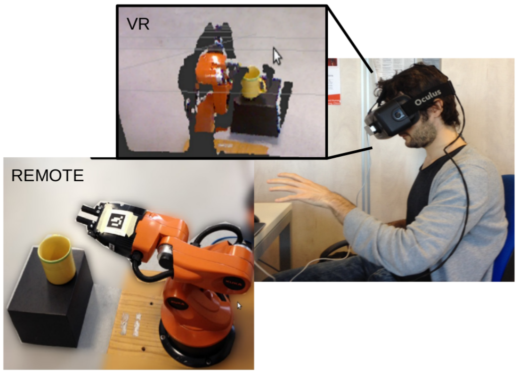

Figure 2: Proposed interaction. The user's setup (right), the 3D view (top) and the robot in the remote scene (bottom left).

3 EXPERIMENTAL RESULTS

To assess the performance of the system we performed several tests switching between the two control modalities. The tests were composed of two different phases. First the user has been asked to move the robot end effector in the direct control mode touching two different spots. During the second phase the user has been asked to define several series of waypoints though which the robot had to move. During shared control mode the robot has been capable on a total of six trials to execute always the 100% of the path, except for one trial in which the 84.85% has been achieved.

4 DISCUSSIONS

During the test for the direct control mode, the robot arm has been able to follow the trajectories defined by the user after the first 5 seconds in which the robot moves to its starting pose. The presence of tracking error is mainly due to difference in workspace between the used robot and the human. During the tests for the waypoint control mode the system has been almost always capable of generating a feasible trajectory among the defined waypoints. Ths highlights how the system performance is dependent on the dexterity and on the workspace of the controlled robot arm. For this reason we noticed the need for a method to assess the difference between the robot and the user's hand workspaces.

5 CONCLUSIONS

We presented a ROS integrated framework for robotic platforms teleoperation with adjustable autonomy. In this framework the human-robot interface is gestures-based. A 3D augmented visual feedback of the environment on the remote robot side is given to the user through a Kinect camera and an HMD. The system performances have been assessed using a KUKA Youbot arm. Manipulation tasks can be successfully carried out with the current system, although the performance is influenced by the workspace and the dexterity of the teleoperated arm. Issues remain about workspace matching between robot and user. For this reason an online algorithm, checking the waypoints reachability, will be implemented. Moreover, the semi-autonomous mode will be improved with the possibility to add more augmented reality information.

ACKNOWLEDGEMENTS

The material is based on work carried out in the TAUM Project co-financed by the European Structural Fund for Regional Development, programme POR CReO FESR 2007-2013 of Regione Toscana

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