Tele-Kinesthetic Teaching of Motion Skills to Humanoid Robots through Haptic Feedback

João Barros, Filipe Serra, Vítor Santos, Filipe Silva

***Abstract*— The control of a humanoid robot is a very complex challenge, especially when models are not available of are very imprecise. One solution is to try learning based on human teleoperation. The main idea is let a user teleoperate a robot with force feedback and, once the user has learnt to manage this not-so-easy task, record his control actions along proprioception of the humanoid during some specific tasks, such as balancing under random perturbation. Then, this set of data relating proprioception and user actions can be used on a learning based computational technique, such as Neural Networks or similar. However, data harvesting during user teleoperation of complex real platforms is itself a demanding task. To reduce risks of teleoperation in complex frameworks, such as dual haptic joysticks, a simulation setup comes in hand, even if the model is imprecise. So, this paper deals with issues related to user operation of one or two haptic joysticks against a real and a simulated version of the platform in V-REP during several tasks of balancing in several different contexts. Data gathering has shown to be possible, and all is ready for the step which will be learning and self balance.**

I. Introduction

Exploring the full potential of humanoid robots requires endowing them with the ability to learn, reproduce and generalize new tasks, as well as adapt a skill to changes in real-world environments. Instead of creating a robot with built-in knowledge of possible states and actions, teaching robots to perform a specific task appears as a crucial demand gaining widespread acceptance. In this context, robot Learning from Demonstration (LfD) is a powerful approach to automate the tedious manual programming in which the robot acquires training examples from human demonstrations [1], [2].

Acquiring teacher demonstrations is a key step when transferring skills from humans to robots through imitation. These demonstration examples can be obtained in many different ways, such as recording state-action pairs whilst the robot is passively teleoperated by a human teacher or, alternatively, recording the data as the robot observes the execution of the desired behavior. The teleoperation approach provides the most direct method for information transfer, but it is rarely used with many degrees-of-freedom (DOF). Mimicking the teacher's motions involves the challenge problem of correspondence. Recent progresses aim to provide more user-friendly interfaces, such as kinesthetic teaching in which the human moves directly the robot's parts [3], [4]. However, kinesthetic teaching applied to a whole-body humanoid robot is not trivial since it requires simultaneous demonstrations on many DOFs.

A relevant topic that has not yet been much addressed in existing LfD approaches is the ability to exploit co-adaptation between the human teacher and the learner robot. Unlike conventional tele-operation approaches, the proposed concept of Tele-kinesthetic Teaching (TkT) refers to a bidirectional interface in which the two actors, human teacher and robot learner, can experience the unique abilities of the counterpart. The promising solution that is addressed in this contribution is to include the human teacher in-the-loop by providing him/her with state feedback on the robot's performance through haptic feedback. Based on the evaluation of performance, the human teacher may provide functional guidance and corrections on the executed behavior.

Currently, we focus on understanding two relevant points: First, how to provide effective feedback to the human operator for circumventing the robot's weaknesses. Secondly, how this information can be used to improve the overall system's performance. On the one hand, the proposed approach is evaluated assuming that the human operator has the absolute control of the robot's actions. However, a semi-supervisor control is possible (and desirable) whenever prior knowledge about a particular task is available. On the other hand, this approach is not expected to require specific prior knowledge on robot teleoperation from the user. However, a user may need to practice the teleoperation skills in order to perform repeatable and coherent experiments.

This paper is organized as follows: Section II details the TkT approach, Section III presents the experimental setup, Section IV describes the implementation of the haptic teleoperation system, Section V describes the some experiments already conducted, followed by a conclusion and perspectives of future work.

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II. TELE-KINESTHETIC TEACHING APPROACH

This contribution presents a new approach for the study, development and implementation of locomotion tasks in humanoid robots that relies on the physical interaction between a human teacher and a learning robot. The user provides demonstrations by physically interacting with the robot through a haptic interface. This methodology enables a natural interface for teaching and sensing in which the user provides functional guidance and corrections, while being aware (*i.e.*, able to “feel”) the dynamics of the system, its physical capabilities and/or limitations.

Although it is possible online learning, ongoing research is concerned with supervised learning in which examples of the desired behavior emerge from the interaction of the robot with the environment supervised by a human teacher in a process of trial and feedback. At the end of the demonstration phase, the system should be able to create datasets that help in developing sensorimotor strategies for humanoid behavior. These datasets include the recording of all sensory information and the control commands guiding the execution of a specified task. After a learning phase, the humanoid robot is expected to achieve robust locomotion without rigorous models, while being capable of evolving and improving progressively and continuously (*e.g.*, a learning technique using neural networks or similar tools of soft-computing). This is the most paradigmatic of the sub-objectives: research in the context of sensorimotor behavior towards systems with the learning capability lacking in a priori rigorous models.

III. EXPERIMENTAL SETUP

A. *Real and Simulated platform*

For this work, both a real and a simulated platform were used. The real platform has been developed in the context of the Project Humanoid from the University of Aveiro (PHUA) [5] and is shown in Fig. 1. The CAD model of this platform has also been imported into the V-REP simulator [6], and served as the simulation test bed, as described ahead. Due to the complexity, and risk, of force-based control of so many degrees-of-freedom, the real platform was controlled with simple motion orders and using a single haptic device, and control with two haptic devices (or more elaborate motions on a single haptic joystick) was applied to the model running in V-REP.

A key feature in the TkT approach is the transmission of some of the proprioception of the robot to the user, and in the PHUA platform the most relevant source of feedback are the reaction forces on the feet, accomplished with load cells installed on the feet (Fig. 2). Communication between the haptic device and the real/simulated platform is carried out by the ROS (Robot Operating System) functionalities.

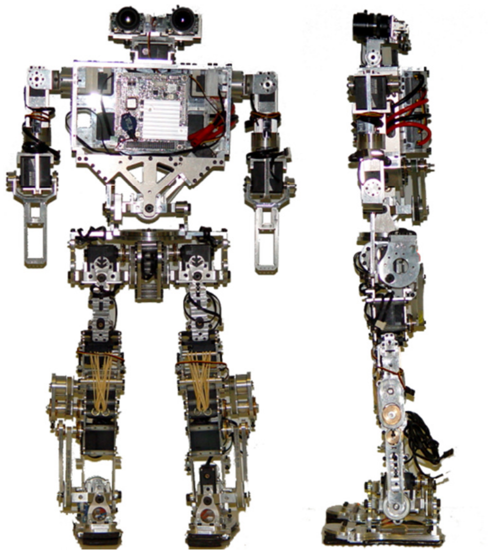


Fig. 1- Front and side views of the full body of the PHUA platform (25-DOF, 65 cm height and 6 kg weight).

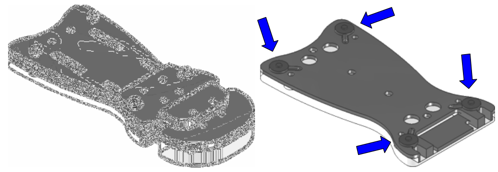


Fig. 2 - Force measurement in the feet: 4 load cells per foot allow obtaining the weight distribution and the estimation of the pressure center.

B. *The software infrastructure*

The haptic device used in this work is a Geomagic Touch (formerly SensAble PHANToM Omni) ground-based haptic joystick. It is basically a 6DOF manipulator, with six rotational joints, capable of rendering three-dimensional force vectors at high frequencies. The software supplied by SensAble is well built and provides all the means necessary to implement the device control, including the device drivers. However, a paired configuration could not be set to work on a single computer. Due to inappropriate drivers, dual Omni configurations are not supported under Linux, the preferred system to run ROS. The solution adopted lies in using two computers, each one responsible for configuring and handling the communication with the haptic device connected to it.

One of the computers will be running V-REP, while ROS modules will be running on both of them. For organization, it is assumed that the master is running on the same machine as V-REP, although this will not affect the system's behavior. Additionally, it is defined that the remaining nodes (responsible for monitoring the robot's state and compute the feedback force), are also running on the second machine for power consumption management, leaving more available resources for V-REP. The experimental setup implemented for cooperative teleoperation of the model is represented in Fig. 3.

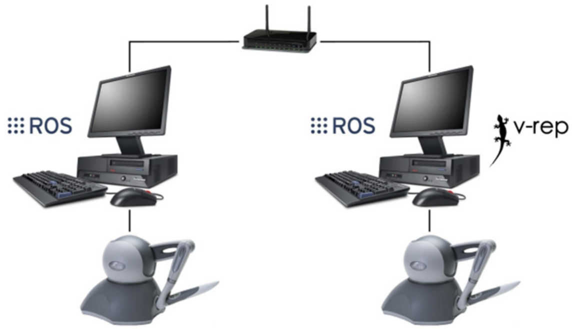


Fig. 3- Experimental setup for cooperative haptics teleoperation.

IV. HAPTIC OPERATION

A. *Joystick data filtering*

User operation on joysticks is to be transmitted to the robot joints. However, raw user data may be unsuited due to limitations of the control units on the robot, besides having the risk of being a liability for system integrity due to mechanical stress of vibration due to poor control setting points. Therefore, user control, in position or in velocity, must be filtered to smooth the action sent to the robot controller. For the experiments carried out, two types of data filtering were implemented, depending on the experiment. First, low pass filtering was used to remove human's hand vibrations or instability when holding the joystick. Second, path filtering was used to impose specific paths (*e.g.*, up-down, or left-right) or by accepting from the user only limited resolutions of slopes in trajectories (*e.g.*, in multiples of 45º). This was mostly concerned with the real platform, but could be used in the simulated environment as well.

B. *Control methodology and kinematics chains*

Concerning the simulated environment, two distinct commanding methodologies are defined for teleoperation: the inverse kinematics and the torque strategies. These denominations arise from the V-REP notation to define the joint operation modes. In inverse kinematics mode (IK), the user controls the hip position in the Cartesian space of V-REP, as the feet are considered to be kept in constant contact with the ground, and at a constant distant from each other. The robot behaves as an inverted pendulum. Its movements are controlled by the location of the joystick's tip, but the IK calculations are entirely carried out by the module existing on V-REP.

When operating in torque mode, each joint is individually actuated as function of its joystick pair. Apart from its normal working position, each joystick can be easily viewed as a robotic leg, containing the primary DOF of a human limb. Thanks to its particular geometry, the PHANToM Omni provides a very interesting match with the robot's DOF, allowing a joint space control according to the joystick's configuration. At the same rate as the simulation receives the information from the joystick and updates its state, it sends information about the robot current state to other ROS modules. These modules will generate a force vector to be reproduced by the PHANToM device, interactively, as the user is controlling the robot, closing the control loop (Fig. 4).

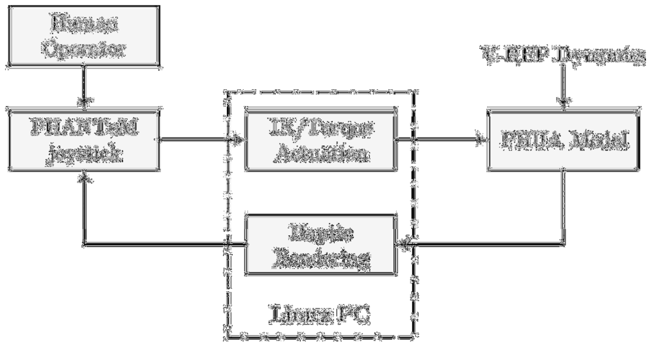


Fig. 4 - An overview of the control loop diagram with the main components of the haptic teleoperation system.

C. *Force feedback calculation*

Force feedback is crucial for proper user sensation of what the robot is feeling in terms of balance. This work implements a general strategy for generating the force feedback based on the ZMP method, which can be applied to both single and double-support phases. The ZMP location defines a practically unavoidable stability margin, relatively to the support polygon limits. Quantifying this margin represents the basic principle involved in the force feedback generation.

The algorithm compares the ZMP position with the real support polygon size and establishes a metric of stability/instability, based on the distance from the support polygon edge to the computed position of ZMP. The force feedback signals synthesized by the joystick are determined by a function that expresses simultaneously the CoP (ZMP) proximity to the robot's foot edges, and its deviation from the most stable position.

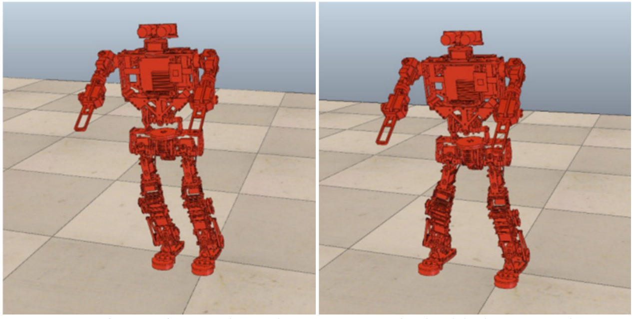
V. EXPERIMENTS

Data logging was performed during experiments and included the following variables: feet force sensors, joints' data, synthesized forces, and user actions on the joysticks.

A. *Experiments with the simulated robot*

Some experiments were conducted to test the accuracy and reliability of the model. With the IK mode there is the intention of reproducing the experiments conducted so far, in order to validate the model and test its accuracy. Known conditions were applied during "ground truth" experiments to refine the model and adjust simulation parameters. Fig. 5 shows two different simulation steps, with the robot being controlled in IK mode, or in Torque mode.

Despite being tested in the simulator, the results of applying such methodologies reveal an underlying consistency with the reality. This shows, in a first stage, that it is possible and relevant the development of an infrastructure to operate the real robot, based on the approach here presented. Although, the success of the teleoperation is highly related with the user's experience.



(a) Inverse Kinematics mode. (b) Torque mode double leg control.

Fig. 5 - Postures of the simulated PHUA during double-support phase.

B. *Experiments with the real robot*

Several experiments were carried out by teleoperating the real robot while receiving robot proprioception in the form of force synthesized in the joystick. One of such experiments consisted of using an industrial robot (FANUC) to create instabilities on the floor plane supporting the humanoid, and the user should try to keep the robot in balance by compensating the force sensations that were transmitted by the haptic device. In the experiments with the real robot, the torso was removed to simplify the experiment and the user's challenges.

The results of this experiment can be seen in two fronts: Fig. 6 and Fig. 7 show the user actions and the synthesized forces; on the other front, Fig. 8 shows the actual outcome of the experiment, which is the real path of the CoP, resulting from the user TkT based operation.

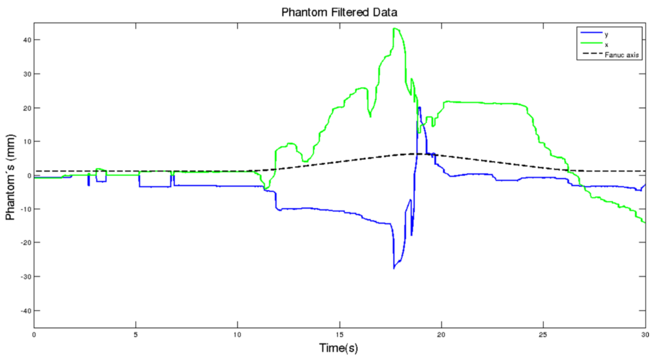


Fig. 6- User actions to try to stabilize the humanoid subject to perturbations.

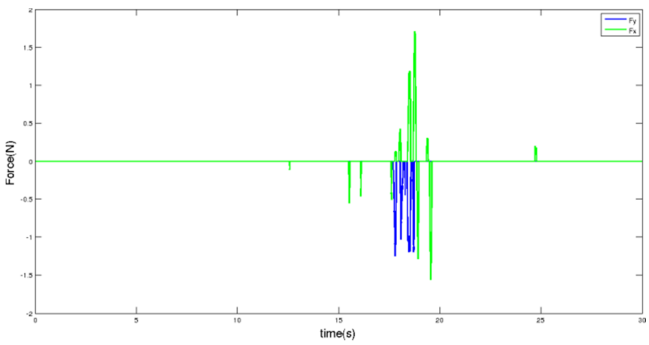


Fig. 7 - Evolution of synthesized forces on joystick during the experiment.

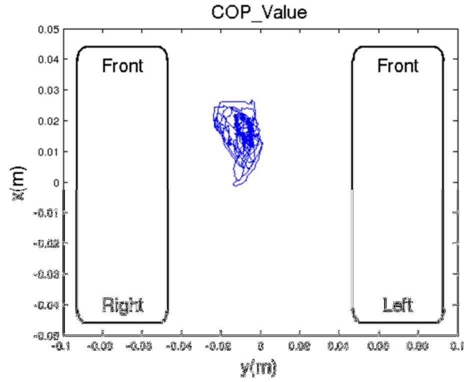


Fig. 8 - Path of the CoP between the robot's feet during the experiment of balance perturbation and the attempt of the user to keep it stable.

VI. Conclusions and Future Work

The tele-kinesthetic approach for data gathering is a challenging task for the user that is expected to teleoperate the robot. However, the preliminary results of the several experiments, both with real robot and simulation environments, show that this methodology has a lot to be explored and can become an excellent tool to obtain data to teach humanoid robots to perform some maneuvers like balancing and eventually locomotion.

The force feedback, properly generated from the robot proprioception, will make the task of learning maneuvers easier, namely those concerning with balance on single and double support phases. A proper learnt balance skill will certainly open the way to start learning the walk gait. This is a step-by-step approach and only future developments will clarify how many steps it will take so a human with his hands can teach a robot to walk with its legs.

Exploring new scenarios and include more challenging external disturbances in the robot teleoperation are within the next goals. The simulation has proved to be a useful tool, providing excellent means to develop the first tests, and real robots are indeed the ultimate tool to obtain the real data for future learning from demonstration, which is now expected to be easier in a soon foreseeable future.

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