PhD Proposal

Humanoid Robot Locomotion Using Haptic and Learning

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CONTEXT

The Humanoid Project at the University of Aveiro (HPUA) is a long-term multidisciplinary research activity that aims to combine mechanical, electrical and computer engineering. The HPUA is the result of a collaborative project between the Department of Mechanical Engineering (DEM) and the Department of Electronics, Telecommunications and Informatics (DETI). The work culminated, in 2009, with the development of a small-sized whole-body humanoid platform based on standard components and open software [1]. This highly integrated robot is oriented for research in biped locomotion, navigation in real-world environments and multi-modal perception for autonomous humanoids.

From a hardware point of view, this research platform has a great potential in terms of movement abilities with 22 degrees-of-freedom (DOFs), low-level actuator control for both position and velocity, and a number of useful onboard sensors (*e.g.*, visual, vestibular and haptic sensory capabilities). However, the control of full-body humanoid robots is an extremely complex problem, mainly for locomotion tasks. This complexity arises from the high number of DOFs to control, the lack of precise models, the non-closed form for robot control, the dependency on environment conditions or the noise in the internal sensors. Compliance of the transmission belts, variable stiffness of the links and small amounts of backlash in the gears make the control task even more difficult. From a software point of view, the main difficulty is to pre-program sophisticated full-body motion controllers for a huge variety of complex tasks the robot system will face in dynamic environments.

Developing the full potential of these robots is only possible by giving them the ability to learn, generalize, adapt and reproduce a task with dynamically changing constraints. In this context, robot learning by demonstration [2, 3] is a powerful approach in order to automate the tedious manual programming of robots, to learn locomotion without complex dynamical models and to reduce the complexity of high dimensional search spaces. The demonstrations are typically provided by immersive teleoperation, use of vision or motion capture systems. Recent progresses aim to provide more user-friendly interfaces, such as kinesthetic teaching in which the human moves directly the robot's parts [4-6]. However, applying kinesthetic teaching to a full-body humanoid robot is not trivial, given the difficulty in performing demonstrations on many DOFs simultaneously, as well as the difficulty of keeping the robot's balance during the demonstration.

This research work proposes a novel approach to study, develop and implement locomotion in humanoid robots, where the user provides demonstrations by physically interacting with a real system through a haptic interface [7]. The proposed methodology enables a natural interface for tele-kinesthetic teaching and sensing in which the user provides functional guidance and corrections, while being aware about (*i.e.*, able to "feel") the dynamics of the system, its physical capabilities and/or constraints. In this context, this approach goes beyond previous research on teaching by demonstration that is unable to raise the level of bidirectional human-robot interaction. Instead, it refers to a deeper relationship between the user and the robot who share control to reach common goals using the same measures of outcome. Furthermore, it is expected that the methodology can be applied in a wide range of other humanoid robots.

OBJECTIVES

The locomotion of humanoid robots is a problem with no definitive solution despite the efforts and developments of last years. The main idea behind this proposal is to use a physical humanoid robot that, while being tele-operated by a human subject using a haptic device, collects and records all sensory information and control commands. 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. In this line of thought, the main objectives of the proposed research are threefold:

1. **To develop a haptic interface for the tele-operation of the humanoid robot**, allowing a human operator to teach and optimize the execution of a specific motor action. In order to achieve this goal several important tasks have to be fulfilled. First, to ensure a natural and intuitive interaction, it will be necessary to define the best way to map the DOFs of the haptic device to those of the robotic system. This task should be performed gradually starting with a simple morphology (*e.g.*, a single-leg) and the progressive involvement of all degrees of freedom. Second, it will be important to adopt the best strategies for translating information about the state of the robot in force feedback to give the system's operator the perception of what is happening to the robot (*e.g.*, robot's balance).
2. **To create real data sets that assist in developing sensorimotor strategies** for humanoid locomotion during the demonstration phase. These datasets include the recording of sensory information and the commands guiding the execution of a specified task (*i.e.*, behavioural examples), using a software architecture suitable for integrating these functionalities (*e.g.*, ROS-based). All the data logged from the human-robot interaction can be later used for learning a compact representation of the task. This objective goes beyond the applications in this work and also intends to provide rich datasets for the international scientific community.
3. **To develop and implement learning techniques for locomotion** based on examples of human demonstrations using neural networks or similar tools of soft-computing. This is the most paradigmatic of the sub-objectives: research in the context of sensorimotor behaviour towards systems with the learning capability lacking in *a priori* rigorous models. During this learning phase, the recordings of demonstrated behaviours are used to extract the correlations among sensorimotor events and to acquire the knowledge of how to select and/or combine different behaviours together.

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