Torque-Controlled Humanoids

Organizers: Andrea Del Prete, Luis Sentis

http://www.codyco.eu/index.php/workshop-humanoids2013

Objectives

In the last ten years we have witnessed a shift in humanoid robotics, from position control to torque control. Humanoids are supposed to be capable of dynamic, high-speed motions. They also need to be sensitive enough to handle fragile objects. Moreover, we want humanoids to be safe, so that they can cooperate with humans. Torque control allows these robots to meet all these demanding requirements.

The aim of this full-day workshop is to advance the current approaches on whole-body motion and force control. The goal is to get an accurate picture of the state of the art and to understand the challenges of the current research. Possible discussions may regard the hardware limitations of current humanoid platforms, and the open-source software implementations of whole-body control frameworks (e.g. iTasc, Stack of Task, Whole-Body Control Framework).

Topics of interest

- Whole-body motion/force control
- Open-source software control frameworks
- Low-level joint torque control
- Robot dynamics modeling
- Whole-body dynamics identification
- Force/torque sensing
- Control of underactuated systems
- Model predictive control for humanoids
- Impedance and hybrid control
- Physical human-robot interaction
- Walking and running
- Nonholonomic motion planning

Invited Speakers:

- Sami Haddadin (German Aerospace Center - DLR, Germany)
- Luis Sentis (University of Texas, Austin)
- Tamim Asfour (Karlsruhe Institute of Technology - KIT, Germany)
- Tom Erez (University of Washington, US)
- Andrea Del Prete (Istituto Italiano di Tecnologia - IIT, Genova, Italy)
- Twan Koolen (Massachusetts Institute of Technology - MIT, Boston, US)
- Federico Moro (Istituto Italiano di Tecnologia - IIT, Genova, Italy)
- Thiago Boaventura (Eidgenössische Technische Hochschule - ETH, Zürich, Switzerland)
- Azamat Shakhimardanov (University of Leuven, Belgium)
- Michael Mistry (University of Birmingham, UK)

Program

Time	Talk
8:45 – 9:00	Workshop introduction (Del Prete, Sentis)
9:00 – 9:30	**Twan Koolen** (MIT, US) – "Whole-body control based on centroidal momentum and motion constraints"
9:30 – 10:00	**Sami Haddadin** (DLR, Germany) - "Intrinsically Elastic Actuation: A Novel Paradigm for High-Performance Torque Controlled Robots"
10:00 - 10:30	Coffee Break
10:30 – 11:00	**Andrea Del Prete** (IIT, Italy) – "Prioritized Optimal Control"
11:00 – 11:30	**Federico Moro** (IIT, Italy) – "An Attractor-based Whole-Body Motion Control (WBMC) System for Humanoid Robots"
11:30 – 12:00	**Azamat Shakhimardanov** (University of Leuven, Belgium) – "Vereshchagin's algorithm for the linear-time hybrid dynamics and control with weighted or prioritized partial motion constraints in tree-structured kinematic chains"
12:00 - 13:30	Lunch Break
13:30 – 14:00	**Thiago Boaventura** (ETH, Switzerland) – "Torque and Impedance Control for Articulated Robots"
14:00 – 14:30	**Luis Sentis** (University of Texas, US) – "Torque Control of Series Elastic Actuated Humanoid Robots"
14:30 – 15:00	Poster Session
15:00 – 15:30	Coffee Break
15:30 – 17:30	**Tamim Asfour** (KIT, Germany) – "Unifying force-based representations for the design of high performance humanoid robots"
16:00 – 16:30	**Tom Erez** (University of Washington, US) – "An integrated system for Model Predictive Control of humanoid robots"
16:30 – 17:00	**Michael Mistry** (University of Birmingham, UK) – "Exploiting Redundancy to Optimize the Task Space"
17:00 – 17:30	Round table and discussion
17:30	End

ABSTRACTS

Twan Koolen (MIT, US) – "Whole-body control based on centroidal momentum and motion constraints"
This presentation introduces a new whole-body control framework, which was used in IHMC's winning Virtual Robotics Challenge entry. The framework is part of a recent trend of online quadratic programming (QP) approaches, in which desired robot behaviors are achieved as closely as possible, subject to friction cone constraints at the contacting bodies. In the presented framework, desired robot behaviors are encoded as linear constraints on the joint acceleration vector, termed motion constraints. Exploiting the properties of whole-body centroidal momentum results in a small QP size, and allows simple high-level locomotion planning using instantaneous capture point dynamics. The presentation will also briefly discuss singularity handling and escape in the proposed framework.

Sami Haddadin (DLR, Germany) - "Intrinsically Elastic Actuation: A Novel Paradigm for High-Performance Torque Controlled Robots"
Intrinsically elastic robots, which technically implement some key characteristics of the human muskoskeletal system, have become a major research topic in nowadays robotics. These novel devices open up entirely new control approaches. These base on temporary storage of potential energy and its timed transformation into kinetic energy. In legged locomotion, such considerations have been a common tool for unveiling the respective fundamental physical processes. However, in arm control, elasticities were typically considered parasitic. In this talk I will outline our efforts in exploiting the inherent capabilities of intrinsically elastic robots in order to bring them closer to human performance. Instead of applying purely kinematic learning-by-demonstration approaches, which are certainly suboptimal, I will argue for using model based techniques together with learning and generalization approaches in order to optimally exploit the system dynamics for highly dynamic motion and manipulation capabilities. In particular, the explicit use of elasticities as temporary energy tanks can be fully exploited only, if being modeled adequately as an integral part of the mechanism. In the long run, one might also argue that such approaches can substantially contribute to the understanding of human motion biomechanics.

Andrea Del Prete (IIT, Italy) – "Prioritized Optimal Control"
In this talk I will present a framework for motion/force control of floating-base systems. The framework is based on the technique of constraint nullspace projection, but differently from previous approaches, this controller can regulate a subset of the contact forces. Special attention has been given to the computational efficiency of the control laws, resulting in a formulation that does not require computing the mass matrix of the robot. Moreover, I will present some results on motion planning for underactuated mechanical systems, by means of prioritized optimal control. We introduced strict priorities into a multi-task optimal control problem, as an alternative to weighting task errors proportionally to their importance. This ensures the respect of the specified priorities, while avoiding numerical conditioning issues

and tuning of the task weights. All the theoretical results have been validated on a simulated 23-DoF humanoid robot, providing also comparisons with other state-of-the-art methods.

Federico Moro (IIT, Italy) – "An Attractor-based Whole-Body Motion Control (WBMC) System for Humanoid Robots"

This paper presents a novel whole-body torque control concept for humanoid walking robots. The presented Whole-Body Motion Control (WBMC) system combines several unique concepts. First, a computationally efficient gravity compensation algorithm for floating-base systems is derived. Second, a novel balancing approach is proposed, which exploits a set of fundamental physical principles from rigid multibody dynamics, such as the overall linear and angular momentum, and a minimum effort formulation. Third, a set of attractors is used to implement both balance and movement features such as to avoid joint limits or to create end-effector movements. Superposing several of these attractors allows to generate complex whole-body movements to perform different tasks simultaneously. The modular structure of the proposed control system easily allows extensions. The presented concepts have been validated both in simulations, and on the 29-dofs compliant torque-controlled humanoid robot COMAN. The WBMC has proven robust to the unavoidable model errors.

Azamat Shakhimardanov (University of Leuven, Belgium) – "Vereshchagin's algorithm for the linear-time hybrid dynamics and control with weighted or prioritized partial motion constraints in tree-structured kinematic chains"

The research introduces a linear-time recursive hybrid dynamics algorithms with partial acceleration constraints by Vereshchagin et al. It presents extensions of the algorithm for priority and weighting based posture and end-effector(EE) control. In order to validate the implementation, simulations were performed. The results compare the setups with conflicting and non-conflicting constraints on the robot's posture and EE. It is shown that conventional controllers are not sufficient for motions involving such constraints.

Thiago Boaventura (ETH, Switzerland) – "Torque and Impedance Control for Articulated Robots"

A legged robot is forced to deal with environmental contacts every time it takes a step. To properly handle these interactions, it is convenient to be able to set the foot impedance, that is, the dynamic relation between the motion and forces generated at the contact point. In addition, in order to obtain a high-performance impedance controller it is desirable to design an inner torque closed-loop controller with as high bandwidth as possible. In this talk, I'll describe some intrinsic physical characteristics that limit the performance in force/torque control, and how to use model-based controllers to compensate for them. Furthermore, I'll show that the torque control loop performance has a big impact in the overall leg passivity, and also that other mechanical issues such as inertia and friction can strongly influence the robot impedance performance. Finally, I'll demonstrate some applications and results obtained with the hydraulically-actuated quadruped robot HyQ.

Tom Erez (University of Washington, US) – "An integrated system for Model Predictive Control of humanoid robots"

I will present an online trajectory optimization method and software platform applicable to complex humanoid robots performing dynamic tasks. Our goal at the Todorov Lab is to construct intelligent feedback controllers based on simple cost functions, without manual specification of the details of the behavior. We achieve this through online trajectory optimization, also known as model-predictive control (MPC), which can be very computationally demanding. Since most of the time is spent computing the dynamics and their derivatives, a fast physics simulator is prerequisite. To this end we have developed a new physics simulator called "MuJoCo" (Multi-Joint with Contacts). In my talk I will demonstrate our interactive environment, which allows the user to modify the dynamics model, cost function or algorithm parameters, while interacting with the controlled system in real time.

Organizers

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