Whole-body Teleoperation of the iCub robot with Multi-task Controllers

Luigi Penco, Brice Clement, Jean-Baptiste Mouret and Serena Ivaldi

I. INTRODUCTION

Current approaches for motion generation and control in humanoid robots essentially rely on optimizers and planners that search for the optimal sequence of joint commands (typically joint torques or velocities) according to an objective function that fulfill multiple tasks under several constraints [7], [4]. In the objective function it is frequent to have tracking tasks, where end-effectors follow a desired trajectory. Unfortunately, designing and tuning the desired trajectories to realize complex tasks is time-consuming, and it often requires the expert knowledge of the controller/planner and of the humanoid kinematics/dynamics, which prevents an easy deployment for new tasks by non-expert users.

An alternative is to follow an imitation approach: a human performs a movement and the robot attempts to reproduce it. Kinestethic teaching is now a mature approach for robotic arms and industrial manipulators equipped with torque sensing: it allows the human operator to show the robot the desired trajectories by physically manipulating the robot body. While this approach is relatively easy nowadays with robotic arms, it can be hardly done with humanoids to demonstrate whole-body movements (because it is not possible to physically manipulate the entire robot at once!). Motion retargeting and teleoperation in this sense represent the extension at a whole-body level of the kinesthetic teaching concept. Transferring the motion from a human operator to a humanoid robot is still a challenging task: first, direct mapping is not possible because of important differences in kinematics (e.g., joint limits, limb lengths) and dynamics (e.g., mass distribution, inertia); second, the robot needs to maintain its balance when imitating the human, so it has to trade-off between imitation and feasibility/safety. This is why kinesthetic teaching with humanoids is a "motion retargeting" problem [5], that is copying the motion from a source (the human) to a target (the robot) in spite of significant differences in their bodies.

This work is motivated by our application in the project AnDy [1], where we are studying human-humanoid collaboration: we would like to show directly to the humanoid human-like movements that represents demonstrations of collaborative policies. In this paper we present our current developments to tele-operate the iCub humanoid robot.

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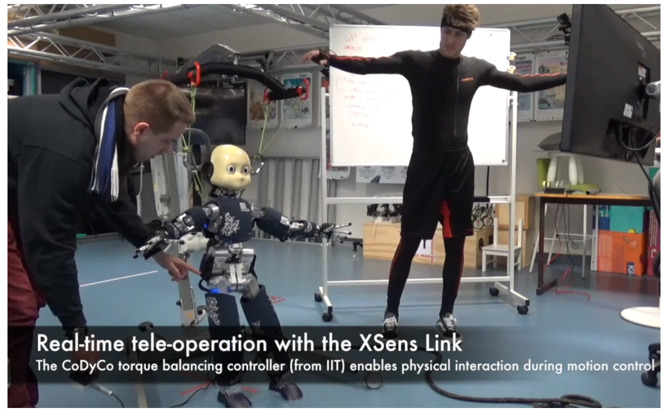

Fig. 1. A typical retargeting experiment with the iCub robot: the teacher (right) is wearing a motion capture suit (Xsens); the robot has to imitate the joint positions while keeping its balance, in spite of the large difference in dynamics and kinematics between the teacher and the robot.

II. MOTION RETARGETING

The first step for a motion retargeting technique is to track the human pose. Recent developments in human motion capture allow now high-fidelity, high-frequency tracking data. Motion-capture is widely used nowadays in various fields including physiotherapy, surveillance, computer graphics and foremost in the cinema, using external cameras or wearable sensors. For our experiments we used the Xsens MVN system [2]. It is a wearable system consisting of 17 IMUs, providing a real-time estimation of the human. Once the data is acquired from the motion capture system, it can be mapped to feasible corresponding values for the robot that are set as references for the multi-task controller.

III. MULTI-TASK WHOLE-BODY CONTROL

We tested two multi-task controllers for controlling the iCub robot: a velocity-based QP controller based on OpenSOT and the torque controller developed in the CoDyCo project.

A. QP control based on OpenSOT

Nowadays, QP controllers have become widespread thanks to their flexibility [3], [4], [5], [6]. QP control for humanoid robots consists in solving, at each control time step, the following optimization problem:

$$\min_{\ddot{q},\tau,\lambda} \sum_k w_k \mid\mid \ddot{y_k} - \ddot{y_k}^d \mid\mid^2$$

subject to:

$$
\begin{cases}
\text{dynamics constraints} \\
\text{contacts no-slip (with environment)} \\
\text{forces within friction cones} \\
\text{joint position, velocity, torque limits} \\
\text{collision avoidance}
\end{cases}
$$

where q denotes the configuration of the robot including its 6D free-floating base, τ are the actuation joint torques, and λ the coefficients of contact forces along linearized friction cones and y the task. Hence QP controllers allow one to easily specify several tasks. For the teleoperation this kind of controllers is the most flexible and safe choice since they allow to take into account both Cartesian tasks (body segment positions) and Joint space tasks while satisfying all the robot constraints. A whole-body QP controller for iCub based on OpenSOT was recently demonstrated for robust balancing in [7].

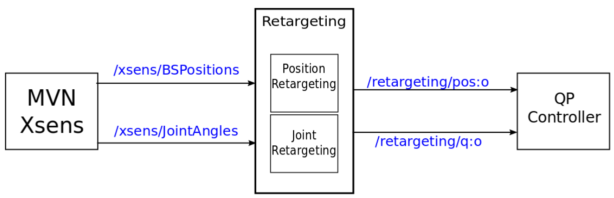

Fig. 2. Retargeting pipeline for the velocity QP control.

B. CoDyCo Torque controller

An alternative strategy is to use a torque based control approach, by computing the minimum torque that minimizes the forces at the contacts [8]:

$$\tau^{\star} = \underset{\tau \in \mathcal{R}^n}{\arg\min} \ || \ f - f^{\star} \ ||^2$$

The torque control allows a more flexible interaction with the robot, in particular it enables direct physical interaction between the human and the robot. For iCub, we developed on the torque controller of the CoDyCo project [9]. However it is quite challenging to include all the problem constraints in that specific formulation and a limited amount of tasks can be expressed (in a hard priority fashion). Furthermore, in the case of iCub, the absence of joint torque sensing[1] and saturation of force/torque sensors limit the torque control loop, to the point that velocity control seems more appropriate for quasi-static movements.

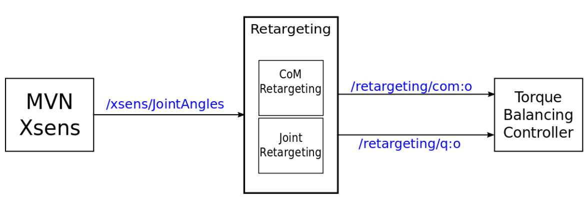

Fig. 3. Retargeting pipeline for the torque control.

[1]Joint torques are estimated online with a mobel-based approach that exploits the sensor readings from the force/torque sensors distributed on the robot [10].

IV. Future Work

One limitation we observed in the teleoperation is that operators sometimes struggle to create motions that produce ”natural” and precise behaviors in the robot. In our view, the next step is to provide to the operator a first-person visual feedback from the robot, so we are working to connect a Oculus Rift system to the cameras located inside the eyes of the robot. Our intuition is that the ”immersive teleoperation”, differently from the simple motion retargeting, will make the task simpler for operators: with practice, they will adapt to the new ”body” and no longer have to struggle to manually adjust their motion to produce ideal motions on the robot. Our hope is that the adaptation and optimization will be done automatically by the human brain in the new virtual or augmented environment. Several studies in neuroscience analyzed the response of our Central Nervous System (CNS) to the simulated reality of virtual environment [11], [12]. They observed how the CNS adapts to it and how robust are these adaptations: exposure to a VE automatically causes sensorimotor adaptation, whether desired or not. These results suggest that we may expect a similar behavior for the operators controlling the robot.

References

[1] Ivaldi, S.; Fritzsche, L.; Babic, J.; Stulp, F.; Damsgaard, M.; Graimann, B.; Bellusci, G.; Nori, F. ”Anticipatory models of human movements and dynamics: the roadmap of the AnDy project”, *Proc. Int. Conf. on Digital Human Models (DHM)*, 2017.

[2] Xsens Technologies B.V. ”MVN User Manual”, *Document MV0319P, Revision T*, 2017.

[3] A. Di Fava, K. Bouyarmane, K. Chappellet, E. Ruffaldi, A. Kheddar ”Multi-contact motion retargeting from human to humanoid robot”, in *Proc. IEEE/RAS HUMANOIDS*, 2016.

[4] K. Bouyarmane, J. Vaillant, K. Chappellet, A. Kheddar ”Multi-robot and task-space force control with quadratic programming”, in *Proc. IEEE Transactions on Robotics*, 2017.

[5] K. Otani, K. Bouyarme ”Adaptive whole-body manipulation in human-to-humanoid multi-contact motion retargeting”, *Proc. IEEE/RAS HUMANOIDS*, 2017.

[6] K. Otani, K. Bouyarmane, S. Ivaldi ”Generating Assistive Humanoid Motions for Co-Manipulation Tasks with a Multi-Robot Quadratic Program Controller”, *Proc. IEEE/RAS ICRA*, 2018.

[7] Mingo Hoffman, E.; Clement, B.; Zhou, C.;Tsagarakis, N.G.; Mouret, J.-B.; Ivaldi, S. ”Whole-Body Compliant Control of iCub: first results with OpenSoT”, *Proc. IEEE/RAS ICRA - Workshop on Dynamic Legged Locomotion in Realistic Terrains*, 2018.

[8] F. Nori, S. Traversaro, J. Eljaik, F. Romano, A. Del Prete, D. Pucci ”iCub whole-body control through force regulation on rigid non-coplanar contacts”, *Front. Robot. AI*, 2015.

[9] Romano, F.; Nava, G.; Azad, M.; Camernik, J.; Dafarra, S.; Dermy, O.; Latella, C.; Lazzaroni, M.; Lober, R.; Lorenzini, M.; Pucci, D.; Sigaud, O.; Traversaro, S.; Babic, J.; Ivaldi, S.; Mistry, M.; Padois, V.; Nori, F. ”The CoDyCo Project achievements and beyond: Towards Human Aware Whole-body Controllers for Physical Human Robot Interaction”. *IEEE Robotics and Automation Letters*, vol. 3 n.1, p. 516-523, 2018.

[10] Fumagalli*, M.; Ivaldi*, S.; Randazzo, M.; Natale, L.; Metta, G.; Sandini, G.; Nori, F. ”Force feedback exploiting tactile and proximal force/torque sensing. Theory and implementation on the humanoid robot iCub”. *Autonomous Robots*, v. 33, n. 4, pp. 381-398, 2012.

[11] Daniel Sjolie. ”Human brains and virtual realities. Computer generated presence in theory and practice”, Doctoral dissertation. Umea: Umea universitet, 2013.

[12] W. Geoffrey Wright. ”Using virtual reality to augment perception, enhance sensorimotor adaptation, and change our minds”, *Front Syst Neurosci*, 8: 56, 2014.