# Whole-Body Compliant Control of iCub: first results with OpenSoT

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## I. INTRODUCTION

Humanoid bipedal robots are becoming more and more popular among the research community thanks to their versatility in terms of locomotion and manipulation capabilities. On the other side, these platforms are, in general, more complex to control than other robotics platforms: locomotion in open and cluttered environments, balancing, whole-body control, redundancy resolution and perception are some of the still open topics in this field. Furthermore, it is very difficult to find mature hardware platforms to perform experiments. Several small-sized humanoids are actually available for purchasing but, for what concern medium (children-like) and large (adult-like) sizes, there are very few companies providing such products [1], [2]. Among the medium size platforms, the iCub [3] is the one with the highest number of working units in the world.

iCub is a humanoid robot with 53 degrees of freedom (DoF), originally conceived for research in cognitive and developmental robotics [3]. After being equipped with force/torque and tactile sensors it became a central platform for whole-body dynamics estimation [4], torque control and physical interaction [5], enabling research in human-robot collaboration and assistance-oriented tasks [6]. In these applications, locomotion, balancing and manipulation are complex and, in general, uncertainties are present due to the unstructured scenario and the presence of human agents. It is well known that such uncertainties can be handled with compliant controllers that permits to manipulate the environment or interact with humans in a safe way and without breaking the robot. In particular, it was shown that compliance plays a crucial role for the stabilization of bipeds when subject to external pushes [7].

In this work we present the integration of a simple compliant stabilizer [8], which acts at the level of the Center of Mass (CoM), together with a whole-body controller [9], in the iCub robot. This integration effort has been made in order to provide iCub with a simple but effective module which can handle whole-body tasks and stabilization at the same time.

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## II. COMPLIANT WHOLE-BODY CONTROLLER

The compliant whole-body controller is divided in two main components: the *Compliant Stabilizer* and the *Whole-Body Inverse Kinematics (IK) Engine*. The *Compliant Stabilizer* is based on the work in [8] and uses a simplified model to stabilize the robot at the CoM. The stabilization is done computing a control input, consisting in a correction of the reference of the CoM, based on the desired vs actual Zero Moment Point (ZMP) position as well as its velocity. Equivalent stiffness and damping gains are used to tune the controller. The actual position of the ZMP is measured using the force/torque sensors at the ankles of iCub. This well known solution is very effective because when the robot has the feet in contact with the environment, the force/torque sensors measure all the possible interactions which the robot is subject to.

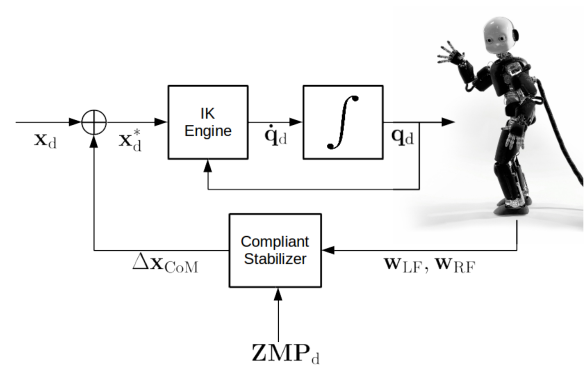
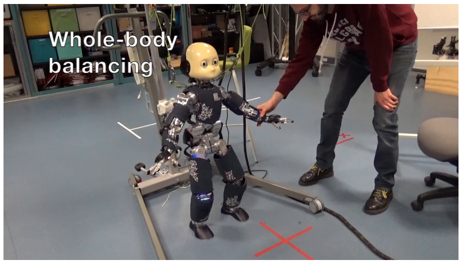
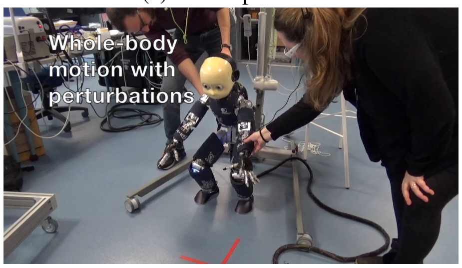



Fig. 1: Proposed control scheme: $\mathbf{x}_\mathrm{d}$ contains all the desired references from the user side. The CoM reference is modified by the *Compliant Stabilizer* which generates a $\Delta\mathbf{x}_\mathrm{CoM}$ according to the desired position of the ZMP (namely $\mathbf{ZMP}_\mathrm{d}$) and the measured wrenches from the feet $\mathbf{w}_\mathrm{LF}$ and $\mathbf{w}_\mathrm{RF}$. The updated references $\mathbf{x}^*_\mathrm{d}$ are *sent* to the *Whole-Body IK Engine* and converted to joint velocities $\dot{\mathbf{q}}_\mathrm{d}$. The output joint velocities are integrated and *sent* to the joint position PID controllers.

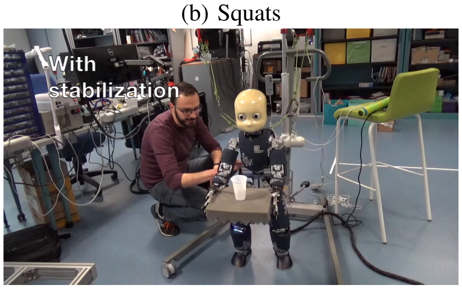
The corrections at the level of the CoM are added to the CoM reference and *sent*, with all the other Cartesian references, to the *Whole-Body IK Engine*. This component is based on the work in [9] and permits to handle priorities between tasks as well as constraints in form of equalities and inequalities. In particular, the *Whole-Body IK Engine* computes, from the Cartesian references, joint level velocities which are integrated and sent to the robot low level PID controllers. OpenSoT permits to easily customize the controller in terms of formulation, tasks/constraints organization and solver. In particular in this wok we have chosen the velocity control formulation, the tasks are organized in the following priorities




(a) Tele-Operation




(b) Squats




(c) Empty glass stabilization

Fig. 2: Experiments performed on iCub using the proposed whole-body control scheme (control loop at 100Hz non Real-Time).

(in particular we are considering a floating-base robot):

$$\begin{pmatrix} \left({}^{\text{World}}\mathcal{T}_{\text{RFoot}} + {}^{\text{World}}\,\mathcal{T}_{\text{LFoot}}\right) / \\ \left({}^{\text{World}}\mathcal{T}_{\text{CoM}}^{\text{XY}} + {}^{\text{World}}\,\mathcal{T}_{\text{Waits}}^{\text{ZO}} + \mathcal{T}_{\text{Neck}}\right) / \\ \left({}^{\text{World}}\mathcal{T}_{\text{RArm}} + {}^{\text{World}}\,\mathcal{T}_{\text{LArm}}\right) / \\ \mathcal{T}_{\text{Posture}} \end{pmatrix} << \left(\mathcal{C}_{\substack{\text{Joint}\\ \text{Limits}}} + \mathcal{C}_{\substack{\text{Joint Velocity}\\ \text{Limits}}}\right) \tag{1}$$

where ${}^{\text{a}}\mathcal{T}_{\text{b}}^{\text{X}}$ represents the X component of a velocity *task* from frame *a* to frame *b* expressed in frame *a* (if frame *a* is missing, the *task* is intended in joint space), and $\mathcal{C}$ represents a *constraint*. the formulation in (1) shows how the *tasks* and *constraints* are organized. In particular the symbol "\" is used to set HARD priority (in terms of null-space projection) relation between *tasks* while the "+" symbols is used to set SOFT priority (in terms of augmentation) between them. Such "stack" enables to move the arms ensuring that the CoM will not change its position, the stabilizer behaves in order to track a desired ZMP reference changing the reference of the CoM. Despite in this work a fixed position for the ZMP is considered, the same control architecture has been used in other robots to realize walking behaviours. Figure 1 shows the implemented control scheme.

## III. Experiments

We consider three set of experiments where a human applies external forces to various parts of the body of the robot.

In the first experiment the robot is balancing while an operator tele-operates the hand end-effectors. The level of compliance is given primarily by the equivalent stiffness and damping gains of the stabilizer. On the other side, the motion behaviour is given by the parameters of the IK engine. The second task consists in squatting motions: here we observed that high compliance along the X axis generates high oscillatory motions, therefore we reduced the gains in the X direction of the stabilizer (which correspond to increasing the stiffness). Finally we consider a typical service task: carrying an empty plastic cup on a tray. Here, we want that the robot to be able to stabilize the object while being subject to external perturbations. The motion behaviour given by (1) permits to stabilize the end-effectors. Of course, considering the order of priority in (1), the arms will move in a way to do not disturb the CoM tracking from the previous task. This is compatible with human-like behaviours: if the robot is subject to very high external perturbation, the main task to satisfy is the balancing (with any limb) than the stability of the plastic cup. Figure 2 shows the setup of the aforementioned experiments, a video is available at https://www.youtube.com/watch?v=W6ug-wtAfTk.

## IV. Conclusion

In this work a simple, yet effective, whole-body compliant stabilizer for the humanoid robot iCub has been presented. The control architecture is based on the feed-back controller in [cite ChenXue] and the whole-body IK in [9]. Experiments of such control architectures have been demonstrated for squatting motions, tele-operation and bimanual-manipulation, all taking into account rejection of external disturbances. An open-source implementation of the compliant stabilizer is available at https://github.com/ADVRHumanoids/compliant_stabilizer, the OpenSoT library is available at https://github.com/robotology/OpenSoT. Future works will integrate walking with manipulation and tele-operation with learning [10].

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