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Whole-Body Compliant Dynamical Contacts in Cognitive Humanoids

Year 3
third year project objectives report

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3.2 Project objectives for the period

3.2.1 Overview

The specificity of CoDyCo relies on the fact that the progress beyond the state of the art is guided by the yearly implementation on the iCub humanoid. Within this context, CoDyCo third year specific objectives were to design and implement the control of whole-body posture while performing goal directed movements. Beyond the activities to achieve this result, other long term activities have been conducted in preparation for the following years objectives. These activities involve human experiments, software infrastructure maintenance and the development of learning/control algorithms.

Task	IIT	TUD	UPMC	UB	JSI	INRIA	
WP1	3	1	0.47	2.29	2.00	-	8.76
WP2	-	1	0.48	7.67	21.69	-	33.00
WP3	-	9.65	14.67	1.85	2.00	4.14	32.16
WP4	6.04	12	1.69	2.15	3.00	2.01	36.59
WP5	12	2	0.05	-	-	-	12.90
WP6	1.5	1	0.31	-	0.44	-	1.81
WP7	-	-	0.13	-	-	0.91	1.04
	22.54	26.65	17.80	13.96	29.13	7.06	**126.26**

3.2.1.1 WP1: toolbox for computing and controlling dynamics of whole-body movements with contacts (UB) The overall goal of this work package is to develop software libraries and software modules to be used as toolbox by the entire project consortium. The expected outcome for the third year were to develop such (shared) toolbox that can be used by the entire group for implementing balancing and reaching controllers with multiple contacts.

3.2.1.2 WP2: understanding and modelling human whole-body behaviours in physical interaction (JSI) There were two main objectives within WP2 for the third year of the project: (i) to continue the work on designing of models for human whole body motion in contact where we focused on reducing the dimensionality of the actions taken by the human motor control apparatus during predictable (Task 2.2) and unpredictable (Task 2.3) perturbations of human whole-body behaviour; and (ii) to investigate how humans interact with compliant environment, to model how the viscoelastic parameters of the environment are represented by human CNS, and to study the factors involved in generalization and adaptation of skills learnt in contact with the compliant environment (Task 2.4).

3.2.1.3 WP3: control and optimization of whole-body motion in contact (UPMC) The objectives of WP3 for the third year of the project are threefold. The first one is to demonstrate the applicability of state of the art whole-body motion controllers, such as the one developed in [**?**] and [**?**], on the iCub robot in multi-contact, goal oriented senarii (Task 3.4). The third one is to start exploring ways to enrich the retained whole-body controllers with the capability to interact with non-rigid environment (Task 3.3). The third one is to keep exploring potential ways of optimally coupling the local, reactive control level and the global, decision making one (Task 3.4).

3.2.1.4 WP4: adaptation, Generalization and Improvement of Compliant Control and Tasks with Contacts (TUD) The goal of WP4 is to endow the CoDyCo humanoid robot control architecture with the core abilities for the adaptation, generalization and self-improvement of both control laws and tasks that involve physical interaction with humans, and the environment. In this context, we propose learning approaches that work in conjunction with the control architecture devised in WP3 and rather complement analytical robotic approaches with on-policy learning than starting from scratch. A core idea behind this work package is that Learning should complement classical approaches and not supersede them.

The third year objectives of WP4 include:

- Novel methods for imitation and reinforcement learning of skills with contact will be devised and tested.
- Learning how to combine elementary tasks by imitation and reinforcement learning. The combinations involved include the learned simultaneous use of elementary tasks, the sequential use as well as the co-articulation of tasks.

3.2.1.5 WP5: systems integration, standardization and evaluation on the iCub robot (IIT) The third year main objective for WP5 was the implementation of a validation scenario consisting of the balancing while performing goal directed actions.

3.2.1.6 WP6: management (IIT) The third year management was primarily dedicated to the project consolidation. Among the main goals the maintenance of the software repository and database.

3.2.1.7 WP7: dissemination and Exploitation (IIT) The main dissemination objectives for the CoDyCo third year were the website maintenance, the dissemination activities and management of the IPR.

3.3 Work progress and achievements during the period

3.3.1 Progress overview and contribution to the research field

All the CoDyCo third year objectives have been attained. Here is a list of the CoDyCo third year achievements.

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3.3.2 Work packages progress

WP1: toolbox for computing and controlling dynamics of whole-body movements with contacts (UB) WP1 objectives were achieved for the third year. In summary, the main accomplishments and impacts for the research community are as follows:

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WP2: understanding and modelling human whole-body behaviours in physical interaction (JSI)

In T2.3 JSI studied mutual learning of human and robot in case of interaction with a compliant environment. A novel method for shared control between the human and the robot was developed to efficiently facilitate the robot skill synthesis for the desired interaction.

In T2.2 and T2.4 UB examined how humans learn compliant force dynamics and modulate their whole-body motions to perform goals in contact with compliant environment. Generalization of learnt behavior was tested by examining the motions in environment with different viscoelastic properties.

In T2.2 and T2.3 JSI and UB performed an experimental study to verify the applicability of the manipulability metrics for analyzing postural control in contact with environment.

Finally, in T2.4 TUD and JSI were finalizing the study examining whether supporting contacts in human arm reaching are planned or are an effect of a reactive controller. UPMC and JSI continued with the experimental study to find a global trade-off arising from the interactions between movement time, cost and accuracy.

WP4: adaptation, generalization and improvement of compliant control and tasks with contacts (TUD) The goal of WP4 is to endow the CoDyCo humanoid robot control architecture with the core abilities for the adaptation, generalization and self-improvement of both control laws and tasks that involve physical interaction with humans, and the environment.

WP5: systems integration, standardization and evaluation on the iCub robot (IIT) The third year WP5 activities have concentrated on the third year validation scenario. A complete description of the scenario can be found in "D5.2 Scientific report on validation scenario 2: balancing on feet while performing goal directed actions." which discusses the technical implementation of the third year validation scenario (see `https://github.com/robotology-playground/codyco-deliverables/tree/master/D5.2/pdf`). With respect to the state of the art the work progress represents a step towards whole-body torque control under postural, contacts and goal-directed constraints. The integration of tactile feedback within the whole-body controller is a peculiarity of the implemented CoDyCo validation scenario and therefore represents yet another step forward with respect to the current state of the art.

WP6: management (IIT) The CoDyCo project continued successfully. Management activities included the definition of a third amendment procedure smoothly organized by the consortium and the project officer. The software repository (`https://github.com/robotology/codyco`) have been significantly improved as clearly documented in the web-based git repository hosting service (`https://github.com`).

WP7: dissemination and exploitation (IIT) Within WP7, CoDyCo third year achievement include: dissemination at relevant academic and industrial events; population of the CoDyCo database to disseminate robot and humans datasets.

3.3.2.1 Work package 1 progress

3.3.2.1.1 Reults 1 Some description.

3.3.2.1.2 Result 2 Some description.

3.3.2.1.3 Resources Overall, the use of resources within WP1 was in accordance to the plans.

WP1 person months	IIT	TUD	UPMC	UB	JSI	INRIA
Year 1	8.67	1.00	3.29	0.51	2.00	-
Year 2	3.00	3.00	0.47	2.29	0.00	0.00
Year 3	NaN	NaN	NaN	NaN	2.00	0.00
Partial	11.67	4.00	3.76	2.8	4.00	0.00
Overall	12.00	9.00	6.00	15.00	6.00	5.00

3.3.2.1.4 Deviations from workplan No significant deviations.

3.3.2.2 Work package 2 progress

3.3.2.2.1 Shared control method in interaction with compliant environment
At JSI we studied mutual learning of human and robot in case of interaction with a compliant environment. A novel method for shared control between the human and the robot was developed to efficiently facilitate the robot skill synthesis for the desired interaction. If the robotic skill is incrementally formed (online) while the physical interaction task is performed/taught by the human demonstrator then the robot has the capacity to generate the control commands for the robot already during the learning stage. However, the human is simultaneously controlling the robot in order to teach it how to perform the given interaction task. Therefore, there can be a conflict between the human commands and commands

generated by the currently obtained robotic skill. To solve this issue, an additional method was developed that delegates the control responsibility between the two acting agents in tasks involving interaction with compliant environment.

While shared control is a well-studied subject in case of pure teleoperation [**?**], only few studies exist in human-in-the-loop robot teaching framework. One of our previous studies [**?**] focused on developing a shared control method for teaching humanoid robot of compliant whole-body interaction with unpredictable environment in online manner. The control was shared percentually between human and robot based on the average error between the demonstrated actions and the actions from the robot over entire task space up until the current observation time. The disadvantage of this method is that the human cannot efficiently inspect the performance of the currently learnt robotic skill in specific subspace (or state region) of the interaction task. In addition, percentually shared responsibility between the two agents makes it hard for the human to determine who is responsible for a potentially bad performance of the task.

To solve the above-mentioned drawbacks we developed a new method, where the control between the two agents is shared based on the existence of local models in the specific subspace (or state region) of the task. If no local models within the robotic skill exist for a specific subspace, where the task is currently performed, then the control responsibility is given to the human so that he can perform the task through the robot body and at the same time teach it. If local models within the robotic skill exist for the subspace where the task is currently performed, then the control responsibility is given to the robot so that the human can inspect its performance. In case the observed performance is unsatisfactory, the human can update the robot in that specific region. The advantage of this approach is that the skill inspection/correction can be done online (during the demonstration stage) without the need to stop the setup, as opposed to offline robot learning where the skill can be inspected only after the demonstration stage, and if corrections are required the demonstration stage has to be repeated.

The control was shared between the human and the robot as [**?**]

$$y_{cmd} = C \cdot y_{demo} + (1 - C) \cdot y_{robot}, \tag{1}$$

where y_{cmd} is a vector of commands sent to the robotic mechanism, y_{demo} is a vector of commands given by the human demonstrator, y_{robot} is a vector of commands produced by the current state of robot and $0 \leq C \leq 1$ is a weight factor that determines the influence of each agent. Pure human control is achieved when $C = 1$, and pure machine control is achieved when $C = 0$.

The practical implementation of the proposed method was done based on Locally Weighted Regression (LWR)[**?**]. LWR is an online machine learning method that approximates the non-linear model of demonstrated skill with a subset of local linear models. Each local linear model is fitted with a receptive field within the state region that determines its domain. The receptive fields are usually realised by a Gaussian kernel functions so that the closer the current input value is to its centre the higher the activation is. In term, higher higher activation of receptive field means higher influence of the corresponding local model on the output prediction. The prediction of output variable y based on some new input variable x is defined by a sum of contribution of all local models, where the models closer to the input variable have higher impact.

In the proposed shared control method the control responsibility between the two agents depends on the activation of the receptive fields of the local models of LWR. If the activation in a given state region is above some predefined threshold w_{th}, sufficient local models exist and therefore the control is given to the robot ($C = 0$) so that the human can inspect its performance. In opposite case, if activation is below w_{th}, no sufficient local models exist and therefore the control is given to the human ($C = 1$) to perform an additional teaching. The method can be expressed as:

$$C = \{ 0 \quad if w_{max} > (w_{th}+\frac{d}{2}) \frac{1+\cos{(\pi \frac{w_{max}-(w_{th}-\frac{d}{2})}{d})}}{2} \quad if (w_{th}-\frac{d}{2}) \leq w_{max} \leq (w_{th}+\frac{d}{2}) 1 \quad if w_{max} < w_{th} \tag{2}$$

where w_{max} is the activation of the model receptive fields [?] and w_{th} is an activation threshold that we introduced to determine the model-proximity based shared control. The switching of responsibility between the human and the robot control is essentially binary to provide the human with a clear feedback about who is responsible for the given task performance. However, we implemented a cosine function to prevent sudden jumps between the two states of responsibility, were d defines the width of switching function.

LWR allows incremental update of local models by feeding a new data point $[x,y]$ each sample time. However, in such case it is hard for human to inspect the robotic skill performance of some subspace of the task as the skill is constantly changing/updating. Therefore we accumulated the training data points for some predefined amount of samples before we fed them to the LWR to update the models:

$$A_{new} = \{ A \quad if C \neq 1] \quad if C = 1 and length(A) < N_{acc} \quad if length(A) = N_{acc} \tag{3}$$

A; [x, y

$$A_{in} = A(randperm(N_{acc}), :) \tag{4}$$

where A is the training data accumulation buffer and the notation A_{new} indicates that A is updated at each iteration. N_{acc} defines the accumulation length in samples before the new model update is made. Before the data is fed to the LWR the training data in accumulation buffer randomly shuffled in A_{in} buffer.

Experimental validation: We validated the proposed method with the experiments on HapticMaster robot [?]. The experimental setup is shown in Fig. **??** left photo. The task of the robotic manipulator was to interact with a compliment environment in a way to produce some desired interaction force. The environment and robotic manipulator were simulated. We constructed a 0.4 by 0.4 m object so that its surface was in x-y (horizontal) plane of the reference frame, where different sections had different stiffness properties. See Fig. **??** right photo for configuration of the object stiffness properties. The parameters were set $k_1 = 100$ N/m, $k_2 = 150$ N/m, $k_3 = 300$ N/m and $k_4 = 500$ N/m. The robotic manipulator had to produce a desired force $F_z = 100$ N along z axis (vertical), which was perpendicular to the object surface. The necessary interaction force control policy was defined as:

$$F_z = K(x,y)(z_r - z_a), \tag{5}$$

where F_z is the interaction force acting between the manipulator and the object surface, $K(x,y)$ is the stiffness of the object in z axis, z_a is actual and z_r is reference position of the

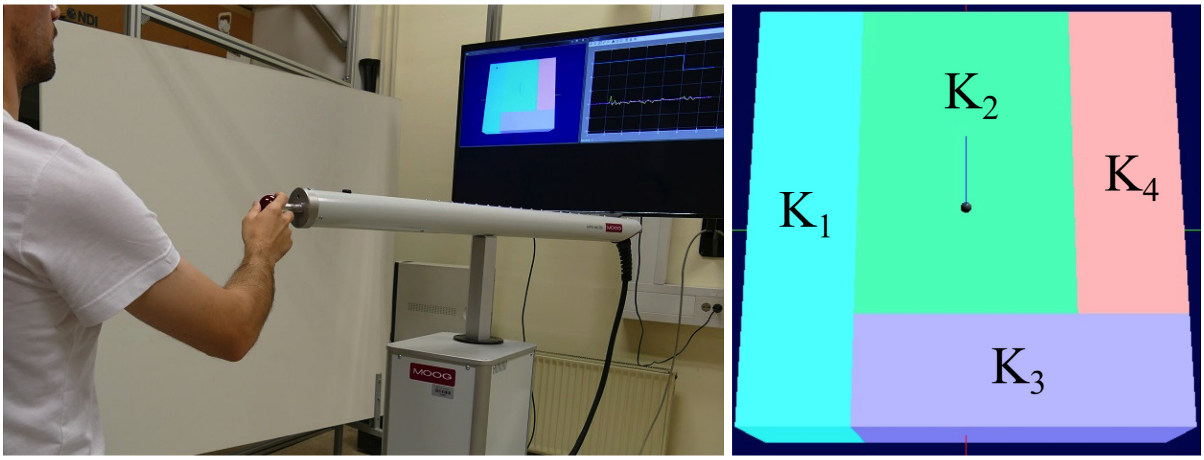


Figure 1: Robot manipulator control interface consisting of HapticMaster robot and monitor for providing human with visual feedback (right photo). Compliant environment with different stiffness properties (left photo).

manipulator's end-effector in z axis. When the manipulator was on the softer section of the object surface (i.e. lower stiffness K), the reference position had to be put deeper inside the object to produce the desired force. In opposite case, when the manipulator was on the harder section of the object surface (i.e. higher stiffness K), the reference position had to be put closer to the surface to produce the same desired force.

The results of the experiment are shown in Fig. **??**. The top row shows the acquired models (robotic skill) for manipulator's displacement of reference position from the actual position in z axis. Each column represents the different stage of training data update. The time stamps of the update application are displayed on the top. The middle row shows the force prediction error of the obtained models at each stage. The bottom row shows the motion of the robot manipulator (thick black and green line) on the surface of the object (thin black rectangle). The black line shows the trajectory when the demonstrator had the control over the robotic manipulator's force production task. The green line shows the trajectory when the robot had the control over the robotic manipulator's force production task. The red crosses show the centres, while blue ellipses show the threshold activation ranges w_{th} of the currently available local models that are part of robotic skill.

3.3.2.2.2 Human motor control learning during compliant interaction with environment In this study performed at UB we aimed to examine how humans learn compliant force dynamics and modulate their whole-body motions to reach anticipated goals. Here, we present an experimental idea to measure the goal-directed movements against compliant forces, and then illustrate the ongoing results which were conducted for a few human subjects. At this pilot stage, we are focusing on the simple linear compliant case and discuss further experiments. To deepen understanding of the mechanism in humans, it would be beneficial to develop the humanoid robot control in interacting with multiple compliant surfaces.

Introduction: Humans can learn how to control their own body movements in an uncertain environment, and utilise it to predict the consequences of actions and to achieve a behavioural goal [**?**, **?**]. A considerable amount of research has shown the human capabilities

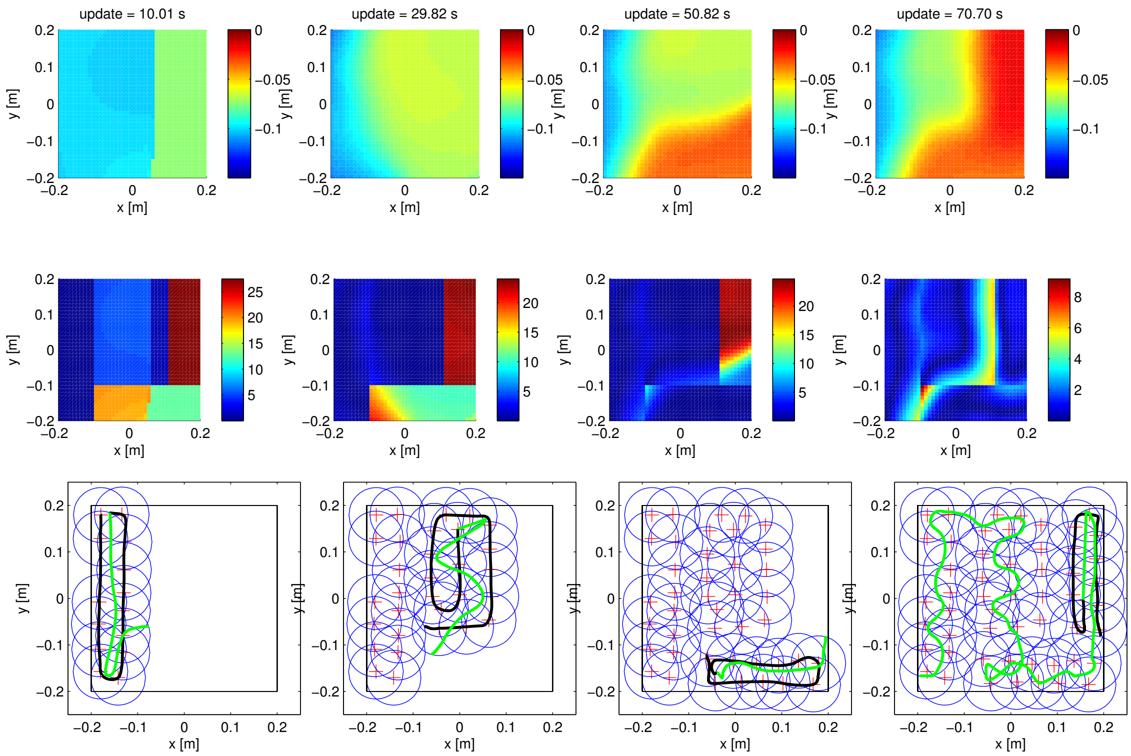


Figure 2: Result of the experiment. Graphs in each column correspond to the stage when the robot was updated. The upper row graphs show the performance of the robot in terms of control of reference position along z axis. The second row shows the error between the reference force and the force produced by the robot. The third row shows the trajectory of motion of robotic manipulator end-effector when the control responsibility was given to human (black line) and when it was given to robot (green line). The influence of local models is shown by blue ellipses and its centres by red crosses.

of generalization in visuomotor learning and has been exploring the underlying mechanisms [**?**, **?**]. A certain exposure to a new physical environment facilitates to generalize the spatial and temporal characteristics of the point-to-point movements via error-based learning and perturbation paradigm. In the real-world interactions, there are varied and complicated force dynamics (i.e., governed by not only simple linear principles) when making a contact with an object and handling it. The optimal functions seem to be perceptually learned via repetitive movements against the force. However, to our knowledge, little is still known about how humans can generalize the compliant force dynamics itself and utilize it to their future motor plan.

The CoDyCo project has been investigating the whole-body coordination mechanisms in arm reaching movements and the postural balance control in assistive contact with rigid and/or compliant surfaces. Like humans, robots are required to flexibly adjust their posture and to coordinate the physical mobility with augmented autonomy. We expect that humans could generalize the force principles in a cognitively robust way via force-feedback from the early stage of the body movements. To explore the generalization mechanism of the force dynamics in humans and to model it would provide a useful strategy in humanoid robot control. The successful model could be exploited to effectively control autonomous robots' whole-body balance in interacting with the environment through supportive contacts.

In a pilot study, we focused on a simple case: linear compliant force. We employed a haptic device, Haptic Master (Moog, Inc.), which is controlled by a set of a computer programmes to render robotic manipulandum for force feedback. The pilot experiment measured the end-effector movements controlled by human subjects and analysed the dynamic properties of the movements against the compliant force and the performance.

Modelling: In general, spring-damper force ($\mathbf{F}$) is formulated by the position and the velocity with parameters: spring stiffness (k) and spring damping factor (λ). Here, it is simplified for one direction ($\mathbf{Z}$).

$$\mathbf{F} = k\mathbf{Z}^n + (\lambda\mathbf{Z}^p)\dot{\mathbf{Z}}\,. \tag{6}$$

We employed the ready-made spring model in the Haptic API, where the compliant force formula was assigned to the device, the Haptic Master. The compliant force was rendered by the end-effector position and the velocity with the parameters in real-time (Fig. **??**).

Experimental design: As a pilot study, we employed a simple linear spring-damper formula:

$$\mathbf{F} = k\mathbf{Z} + \lambda\dot{\mathbf{Z}}\,. \tag{7}$$

The compliant force formula is assigned to the model in the Haptic Master. Aiming to simplify analysing the performance, the forces and the movements were constrained in the only one direction, here, in the vertical (Z) direction to the ground.

Human subjects learned a spring compliant force via repetitive reaching movements to the first target ($z = t_1$) in a certain period of time, - so called "Learning session". Then, they were asked to move the end-effector to the second, or test, target ($z = t_2$), which was set more far from the t1 position, as a test trial; so, more force would be required for this movement (Fig. **??**). In order to achieve the t_2 target, the participants would exploit their prior knowledge of the force dynamics experienced via learning session. We will evaluate whether and how the motion performance is likely to follow the formula previously learned.

Apparatus and Stimuli: The haptic device, "Haptic Master" consisted of a large robotic rod with an end-effector. The "Home" position, where was the centre of the end effector is $z = 0$ at the workspace, was 110 cm from the ground. The spring position was set at $z = 0$. In this study, the rod movements were restricted in the vertical direction only.

The visual information about the task was provided at the computer display to human subjects. The computer screen was located at the right side of the Haptic Master from the subjects; where the centre of the screen was approximately 80 cm from the centre of the robotic rod. The screen was approximately 1 m away from the participants' standpoint, and 80 cm away from the centre of the end effector position. The screen displayed the target position and the end-effector position in real-time (Fig. **??**). The target positions were set at $z = t_1$ (50 mm for learning), and $z = t_2$ (100 mm for test).

Participants: Six male subjects (age: 28.8 +/- 3.1 (SD), height: 175.3 cm +/- 7.1 (SD), weight: 79.5 kg +/- 17.8 (SD), one left-handed) voluntarily participated in the pilot experiment. All had normal or corrected to normal vision, and they had no known motor deficits and/or any limb injuries (self-reported). They were recruited from the student and

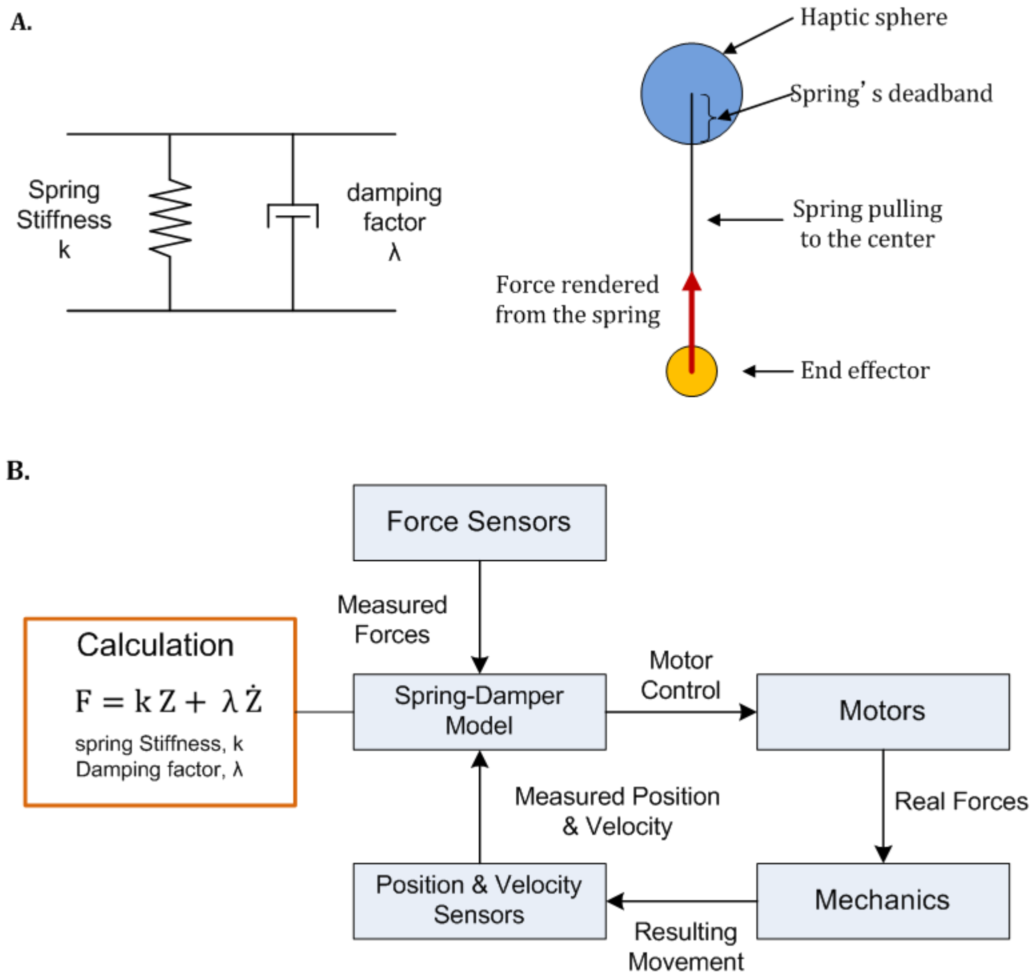


Figure 3: A. The ready-made spring model in the Haptic API. B. Block diagram of the compliant force control. The force is rendering based on the end-effector position and the velocity with parameters (spring stiffness and damping factors) in the real time.

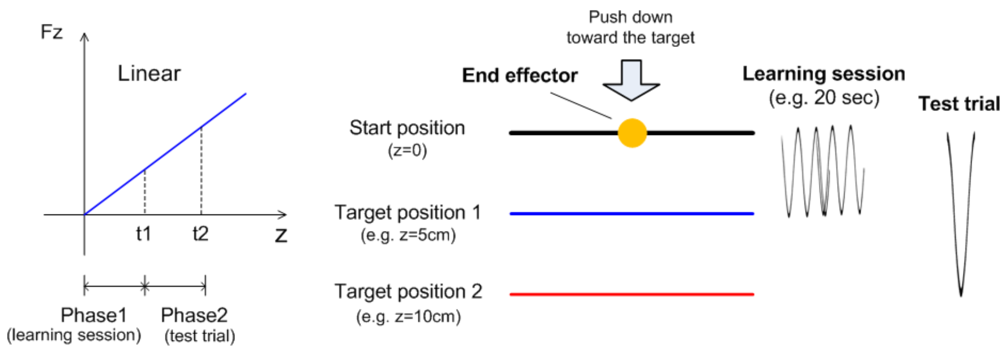


Figure 4: Experimental Design. Two target positions were set: $z = t_1$ for learning session and $z = t_2$ for test trial.

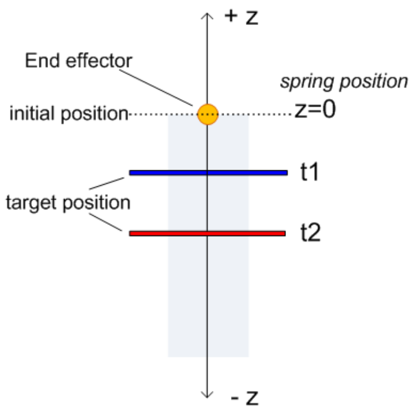


Figure 5: Experimental visual stimuli. The end-effector and the two target positions ($z = t_1$ and $z = t_2$) were visually indicated on the computer screen.

staff population at University of Birmingham. (One was not nave to the purpose of the experiment.)

Procedure and analyses: Participants stood in front of the haptic device and grasped the end-effector. Firstly, they conducted a practice session followed by the main blocks. They were required to make repetitive movements against compliant force generated by the device to learn the kinetic principle. The movements were monitored by visual information on the screen. Participants pushed the end-effector to reach the target position, and then released the end-effector to allow it to freely return to the initial position (z=0). They were asked to set the centre of the end-effector position on the target as accurate as possible.

The main block consisted of two parts: Learning session and Test trial. In the Learning session, the target position was set at $z = t_1$, described above. Participants controlled the end-effector by their own timing, or rhythm, per each movement in the current pilot study (the specific time windows were not set up by the programme for the series of movements: i.e., push the end-effector down from the start position and reach the target position). The visual feedback was given when the end-effector reached to the target; the target colour indicated this by changing from blue to yellow. Participants learnt the compliant force dynamics by the repetitive movements. he experimenter monitored the elapsed time using a stopwatch, and verbally informed the end of the session when 20 seconds passed. Participant stopped their repetitive movements immediately and prepared for the trial session.

In the Test trial, participants moved the end-effector to the target (coloured red line, $z = t_2$) three times based on the formula they previously learned. In this phase, no visual feedback in the relationship between the end-effector position and the target was given to the subjects.

One block consists of three sets (Learning session + Test trial). Participants conducted three blocks; so, 3 blocks in total, and 9 test trials. Under the current settings, the experiment was completed within approximately 20 minutes on average.

The dynamic properties of the point-to-point movements were measured: the end-effector's position ($\mathbf{Z}$), the velocity ($\dot{\mathbf{Z}}$), and the force ($\mathbf{F}_Z$) across the time. These were recorded by the 20 msec sampling rate and the properties were analysed and compared between the linear and the non-linear force conditions.

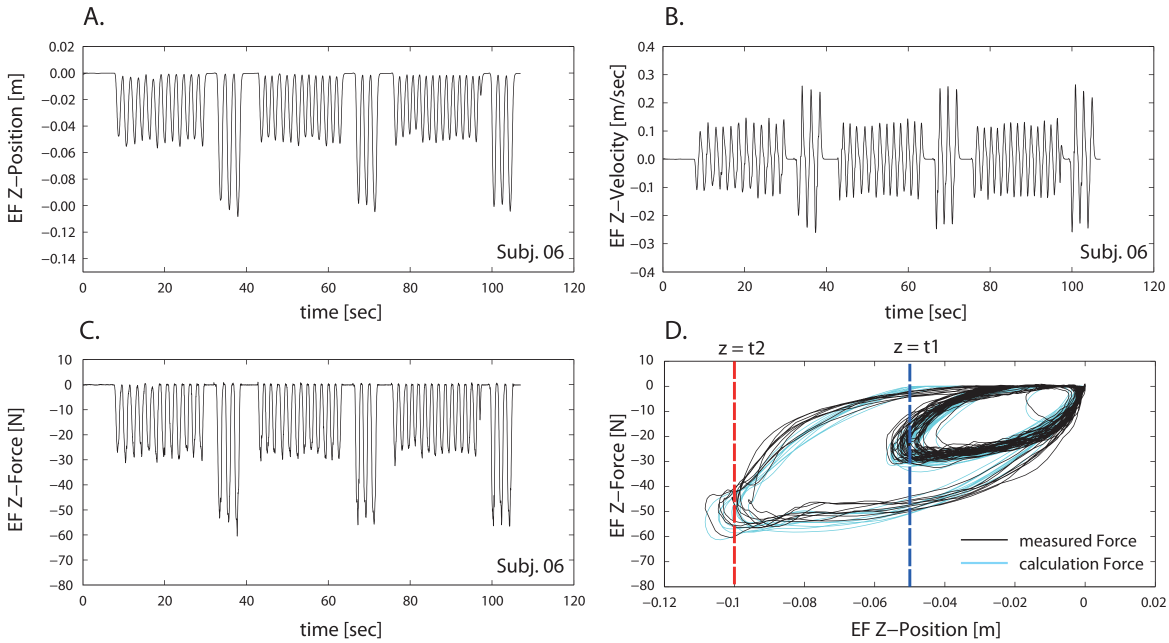


Figure 6: The total recording of the completion of the first block. (Subj. 06). **A**. End-effector Z-position, **B**. Z-velocity and **C**. Z-force. **D**. the relationship between the position and the force compared between the force directly measured by the sensor and the force calculated by the equation with the real time z-position and z-velocity.

Results: The end-effector position, velocity and force were recorded. Here, illustrates the one participant's one block performance, as an example (Fig. **??**).

In order to examine the each reaching movement, the data were extracted from the total between the start ($z = 0.01m$) and the end (approx. $z = t_2$) positions, where the end-effector was released to return to the initial position. These points were determined by calculating the each inflection point (Fig. **??**).

The data were averaged across three blocks; one block consisted of three (Learning + Trial) sessions; so participants ideally completed 9 sessions in total, but one (subj.03) accidentally completed only two blocks because of the setting errors. The averaged numbers of repetitions were 152.8 +/- 45.6 (SD) in the Learning session and 27.2 +/- 6.1 (SD) in the Test trial. All six participants' averaged data (the end-effector position, velocity and force) can be seen from Fig. **??** to Fig. **??**.

Discussion: The **??** showed that some participants (e.g., Subj.01, Subj.06) performed to reach the target position ($z = t_2$) much faster than the expected time duration, which was estimated from the linear equation. That is, the t_2 position was double distance of the t1 from the start position; so the reaching time would be estimated close to the double. The time would not be able to calculate by the simple linear calculation because the damping factor depends on the velocity, though.

This might be caused by the experimental design; that is, participants made the repetitive movements with their own rhythms at the learning session. Because they tend to keep their rhythms even in the consecutive trial session, and then they might have unconsciously increased the force or accelerated their speed to reach the target. This possibility can be seen at their

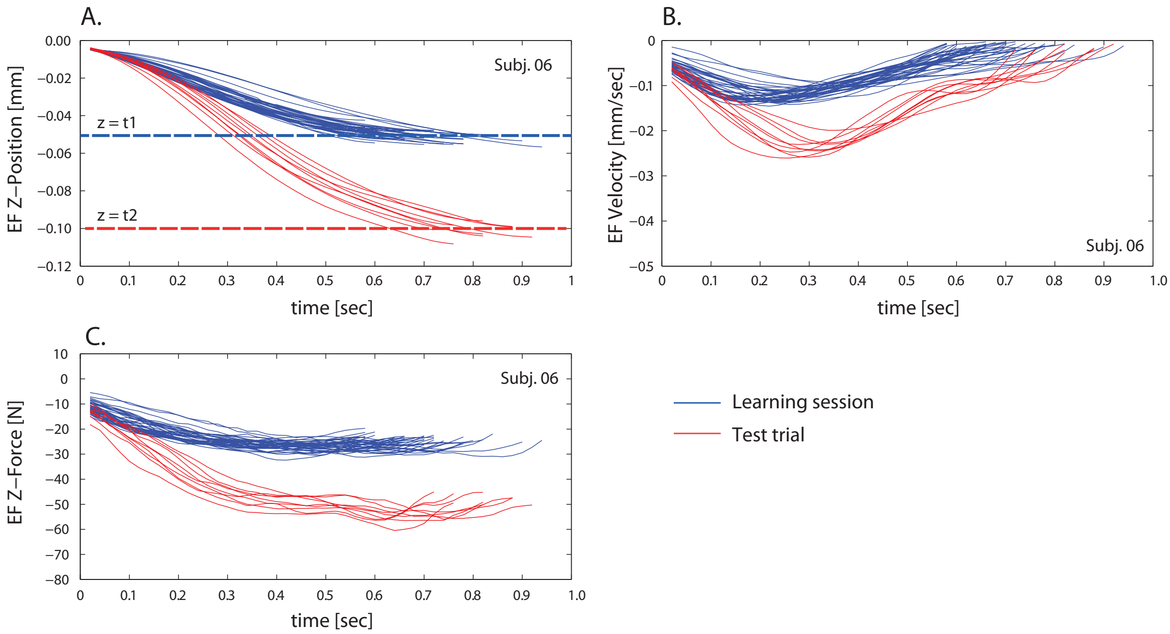


Figure 7: Experimental data for one participant (the first block, three test trials). Red lines represent the forces, which were directly measured by a sensor at the end-effector. Blue lines represent the forces, which were calculated in the real time by spring stiffness and damping factor with the end-effector position.

movement profiles (Fig. **??**: velocity and Fig. **??**: force). Several studies have shown that time perception plays an important role in human motor control [**?**, **?**]; therefore, this timing issue should be carefully considered into the experimental design and should avoid any confounding factors. To do this, we will visually guide the participants' movements with a certain time-windows in the future experiment.

Moreover, in the current pilot experiment, the judgment of reaching the target was inaccurate. Although the participants received the visual feedback at the learning session, it only indicated the end-effector crossed the target position, and also there were no task reward. The inaccuracy would have affected their force perception and movements [**?**] therefore, in the next experiment, we will set a specific correct zone visually defined by a more accurate way (e.g. the similar size of sphere of the end-effector) as the target instead of the line indicators. The task completion in the Learning session would be determined by their performance and individual learning level would be evaluated by their correct movements.

The current analyses conducted for all performance in the test trial (reaching the target ($z = t_2$) three times for each), but the performance might have needed to be evaluated focusing on the first trial only, because the first movement was directly affected by the learning session and the second and the third movements were gradually contaminated.

Overall, through the pilot experiment, we have learned the importance of the timing issue in interacting with compliant surface. We will improve the experimental design and strictly control the parameters (timing, speed, and the accuracy).

In the future experiment, based on the linear case, we will measure the pattern under the non-linear compliant forces and examine the human goal-directed performance. Besides, as

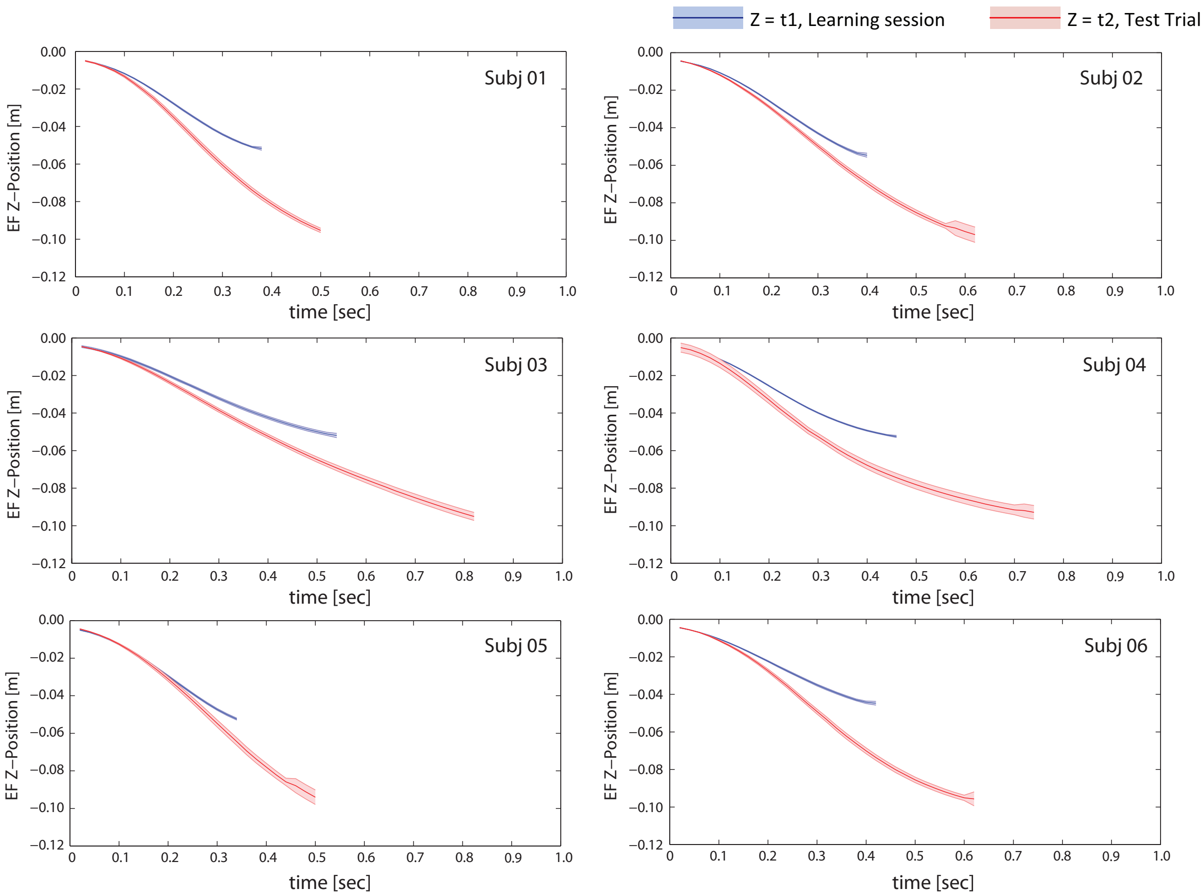


Figure 8: The averaged end-effector z-position performance in the reaching movements against the linear spring-damper force for 6 subjects. The data were averaged across 3 blocks (9 (Learning + Trial) sessions). The blue lines represent the average performance in the Learning session, and the red in the Test trial, the coloured areas represent their standard error respectively.

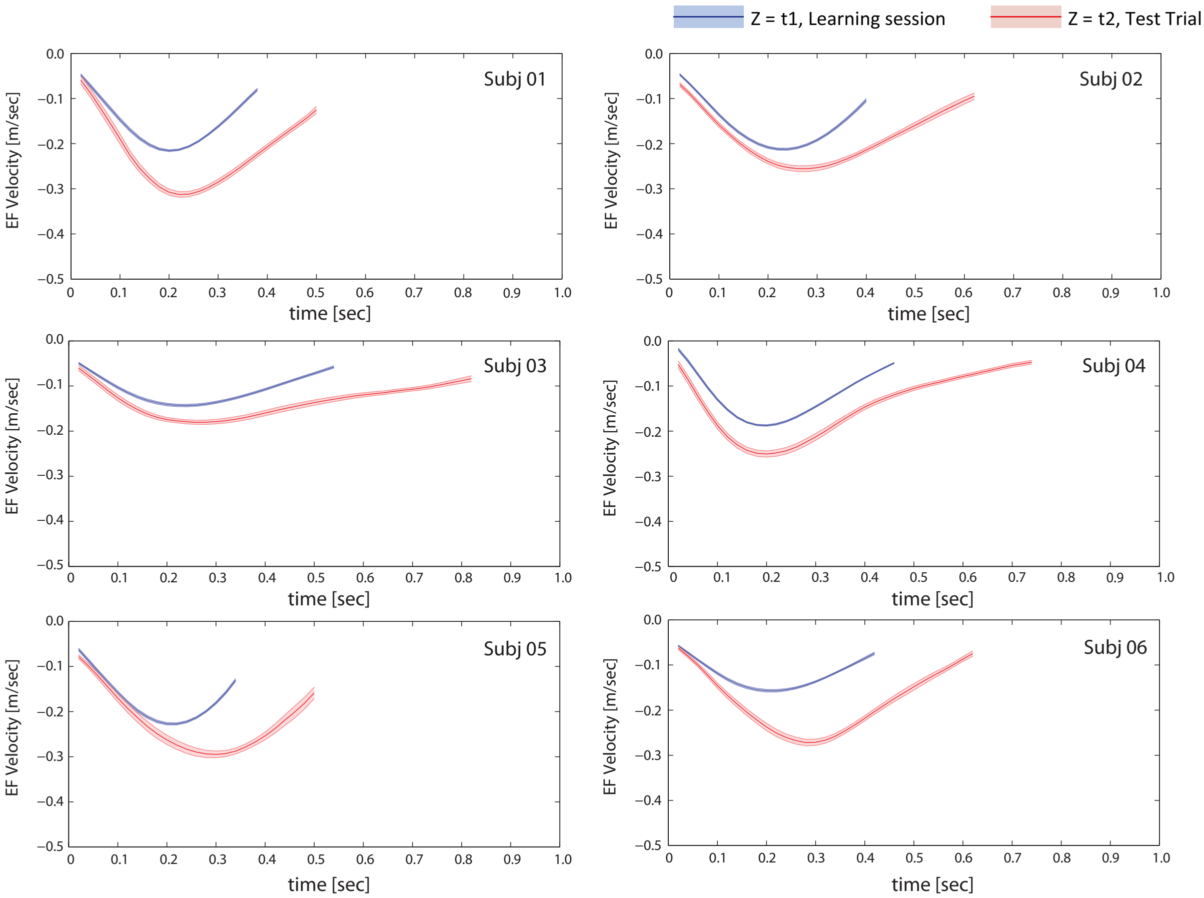


Figure 9: The averaged end-effector z-velocity performance in the reaching movements against the linear spring-damper force for 6 subjects. The data were averaged across 3 blocks (9 (Learning + Trial) sessions). The blue lines represent the average performance in the Learning session, and the red in the Test trial, the coloured areas represent their standard error respectively.

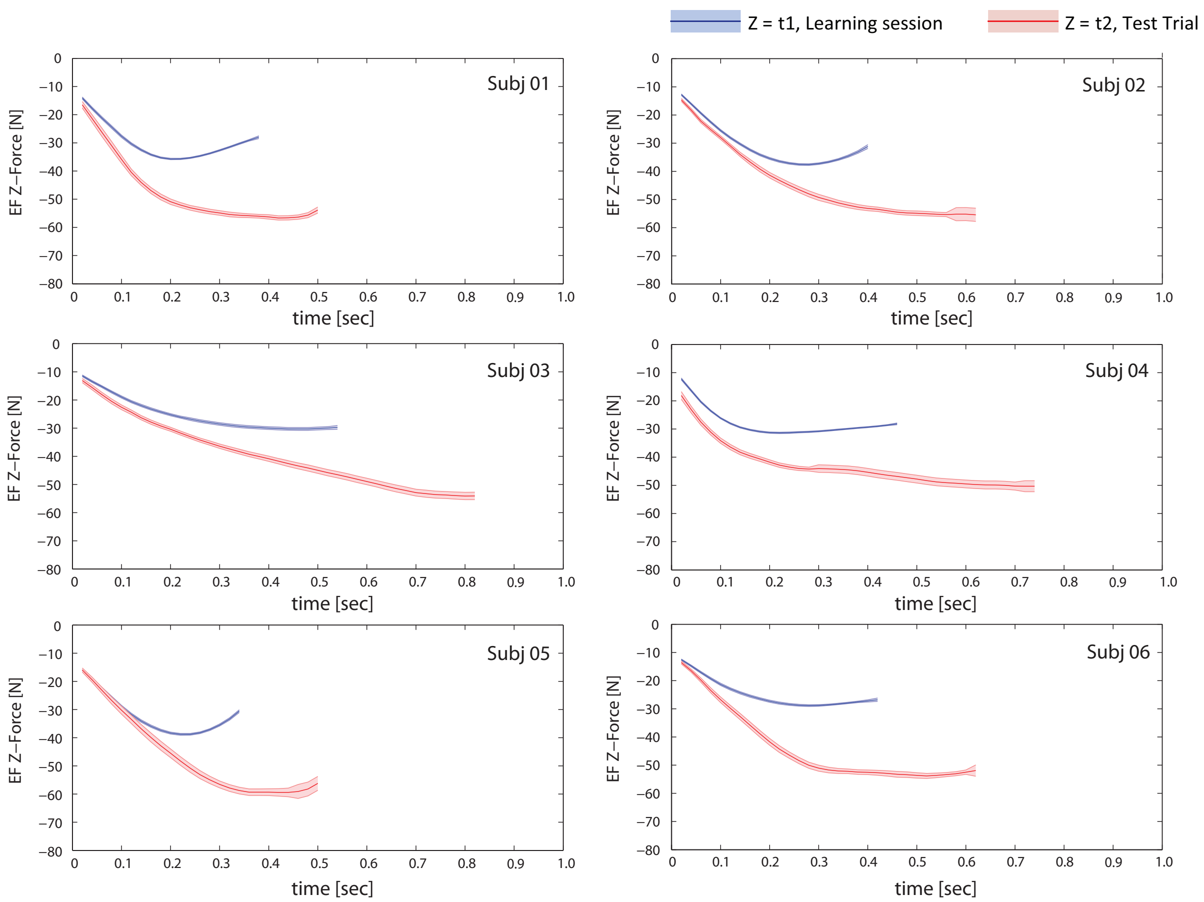


Figure 10: The averaged end-effector z-force performance in the reaching movements against the linear spring-damper force for 6 subjects. The data were averaged across 3 blocks (9 (Learning + Trial) sessions). The blue lines represent the average performance in the Learning session, and the red in the Test trial, the coloured areas represent their standard error respectively.

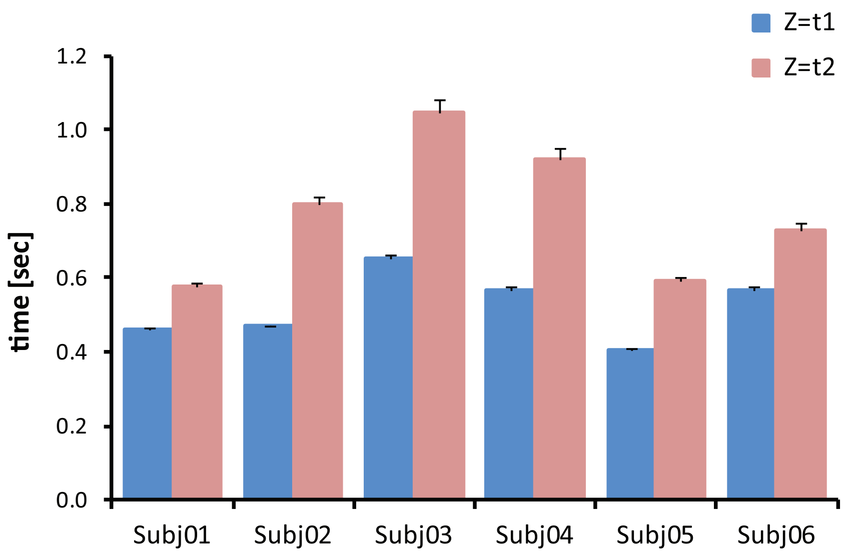


Figure 11: Illustrate averaged time to reach the targets with the comparison between the Learning session (blue) and the Test trial (red) for six subjects. The error bars represents the standard error across the total number of the repetitions.

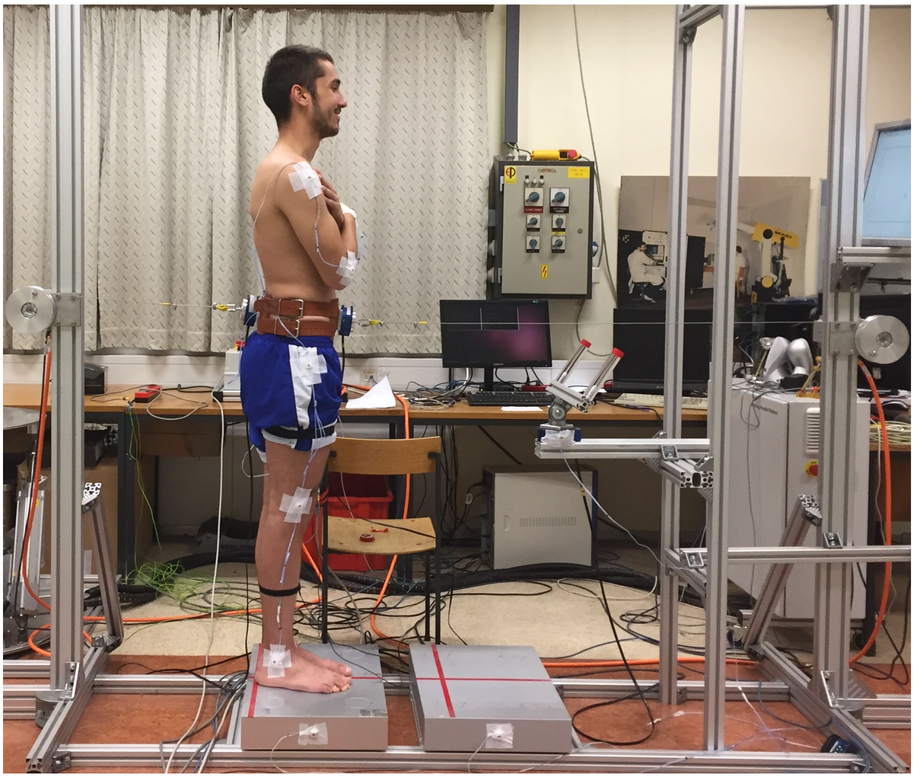
well as the spring-damper, it may help the understanding of the generalization if we employ another compliant force model (e.g. object surface).

3.3.2.2.3 Experimental validation of CoM manipulability metric (Task 2.2 Task 2.3) After the introduction of a set of metrics for studying, analyzing and measuring the ability of humans and humanoids to balance, we performed an experimental study to verify the application of this metrics for human postural control in contact with the environment. In the experiments, the posture of human subjects were perturbed in different configurations and joint torques were computed by inverse dynamics calculations. We demonstrated that the metric is suitable for comparing different postures in the sense of the total required effort for the maintenance of balance.

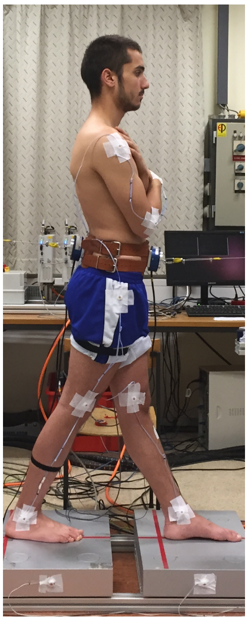
Human experiments: To verify the application of the *change-of-velocity—unit joint impulse* ellipsoid for human studies, we performed experiments on human subjects. As already mentioned, this ellipsoid can be used to measure torque efficiency in balancing motions. So, in the experiments, we perturbed the CoM of the subjects (by a cable-pulley mechanism) in different configurations and measured the contact forces/moments with force/torque sensors (see Fig. **??**). Then we calculated the average total torque that was done by the subjects at each configuration and compared them with the results of manipulability analysis. These steps are described in the following subsections.

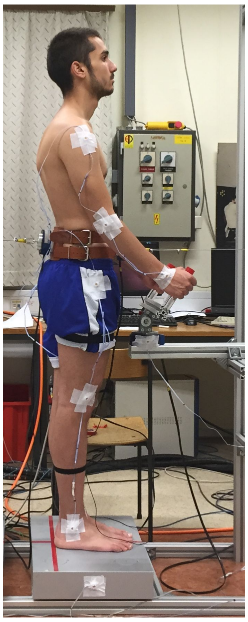
Methods: Eleven healthy male subjects participated in this study. Their average age was 21.7 years (SD $= 2.2$ years), height $= 183$ cm (SD $= 4.6$ cm) and body mass 76.8 kg (SD $= 8.1$ kg). The subjects were informed about the course of the study prior to their participation and were required to sign an informed consent approved by the National Medical Ethics Committee (No. $112/06/13$).

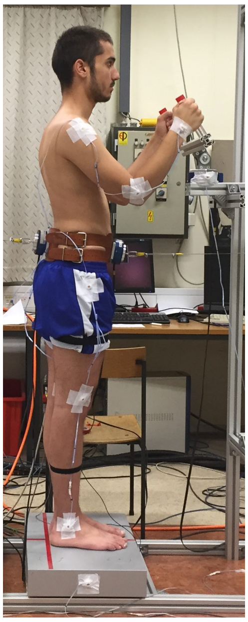
We observed the subjects reactions to the external perturbations in five different poses. In the first pose (*stance*), subjects were standing straight with their feet together and arms

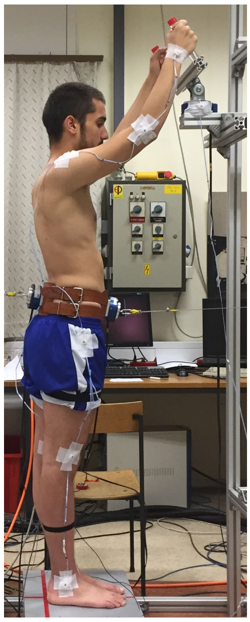


(a)









(b) (c) (d) (e)

Figure 12: Experiments setup for five different positions: (a) stance, (b) wide stance, (c) low handle, (d) middle handle and (d) high handle. A pulley mechanism, which is connected to the subject by a belt, perturbs the subject's CoM. Contact forces are measured at the feet and hands. Motion is recorded with an optical motion capture system.

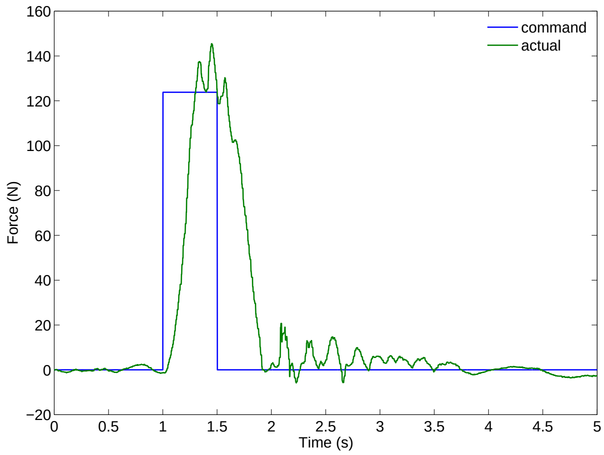


Figure 13: An example of the perturbation force applied to the CoM of the subjects. This is for the subject whose body mass is 76.5 kg. The intensity of the perturbation is number 6 meaning that the force is $6/8$ of the maximum for this subject.

crossed over the torso (Fig. **??**.a). In the second pose (*wide stance*), subjects were standing with their arms crossed over the torso and their left foot 60 cm ahead of their right foot (ankle to ankle distance). In the third pose (*low handle*), subjects were standing as in the first pose and holding the handle which was located in front of their bodies at the hip height (Fig. **??**.b). In the fourth pose (*middle handle*), subjects were standing as in the first pose and holding the handle which was located in front of their bodies at the shoulder height (Fig. **??**.c). In the last pose (*high handle*), subjects were standing as in the first pose and holding the handle which was located in front of their bodies and above the head (Fig. **??**.d).

The subjects were perturbed by a horizontal external force produced by our force-controlled pulling mechanism [**?**] at the approximate position of their CoM [**?**]. The command signal was a step with 0.5 second width (see Fig. **??**). The actual perturbation force was controlled by a combination of a feed-forward and a PID feedback controller. We selected eight linearly increasing magnitudes of perturbation forces where the maximum was defined as 22% of the individual subject's body weight and the minimum was $1/8$ of the maximum force (increasing rate of $1/8$ of the maximum). Between each perturbation we induced a random pause. For each pose, we repeated the series of eight perturbations ten times (80 trials per subject per pose) and observed the human reactions. We gave the subjects 10 minutes pause between each pose. In case of the first pose, the subjects had to step before the maximum perturbation was reached. When the subject made a step, the experimenter stopped the procedure and moved to the next series of perturbations. The step was not required in other poses and the series of perturbations repeated uninterrupted.

Body movements were measured by a motion capture system (3D Investigator™ Motion Capture System, NDI, Waterloo, Ontario).The optical markers were placed on the ankle, knee, hip, shoulder, elbow and wrist. The positions of the markers are used to calculate the joint angles. We used two force plates (9281CA, Kistler Instrument AG, Winterthur, Switzerland) to measure the ground reaction forces and center of pressure position. The handle was mounted on a 3-axis force sensor (45E15A, JR3, Woodland, USA) to measure the force between the handle and the subject.

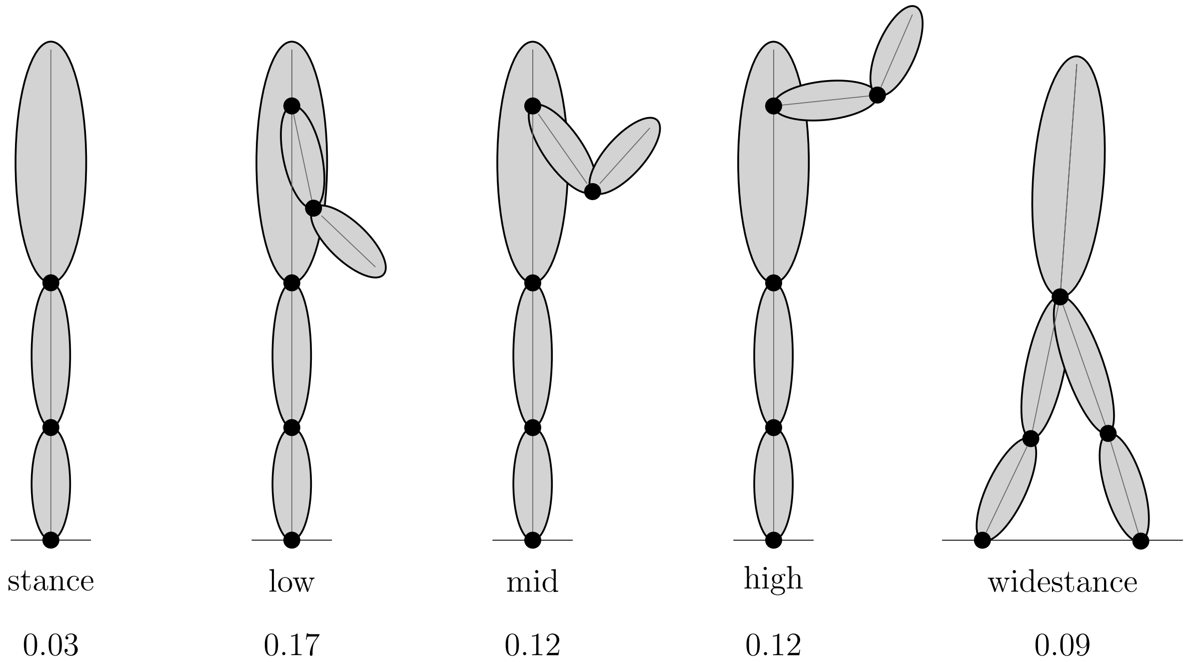


Figure 14: Schematic diagram of the planar humanoid robot model.

In order to estimate the starting time of the subjects' reactions, we measured muscle activation in Triceps Brachii, Soleus and Tibialis Anterior by surface electromyography (EMG). We placed surface EMG electrodes (SX230 EMG sensor,Biometrics Ltd, Newport, UK) on the selected muscles in accordance with SENIAM recommendations [**?**]. We also placed a monitor in front of the subject to provide visual feedback on the CoP position that allowed him to move back to the initial pose after each perturbation.

Model: In the experiments, in order to produce movements which are planar only, we prevented applying out-of-plane forces/moments to the subjects by providing a pair of handles for them and perturbing them in a plane. Therefore, we could use planar models for both inverse dynamics and CoM manipulability calculations. Although, using a planar model for wide stance pose is a bit unrealistic. Planar humanoid models that we used for the stance, wide stance and all three handle poses are shown in Fig. **??**. These models consist of multiple links which are connected to each other by actuated revolute joints. Note that lower legs are connected to the ground. This is because we assume that the feet of the subjects do not move during the experiments. To model the stance pose, we lock the DoF of the arms. So, in this case, the model has 3 DoF and is unconstrained. For the wide stance, the robot has 6 DoF and is constrained due to the kinematic loop in the legs. For the handle poses, the robot has five actuated DoF and it is constrained at the hand to model the handle contact.

Since for balancing we are only interested in movements in the horizontal direction, we calculated the maximum value of $\Delta\dot{\mathbf{c}}$ in this direction for all five positions. This represents the maximum achievable change of velocity of the CoM in the horizontal direction and is a measure for the ability to accelerate the CoM in order to correct its position in this direction. Joint angles of the arms for the handle positions are set to the average initial joint angles of the subjects that we calculate from the marker positions. For the low handle, the shoulder angle (angle between torso and upper arm) is 12° and the elbow angle (between upper and lower arms) is 145°. Shoulder and elbow angles are 35° and 77° for the middle handle, and 96° and 118° for the high handle positions, respectively. For the wide stance position, we assume zero angles in the knees and upright torso. The weighting matrix that we use for the calculations is a diagonal matrix as

$$\mathbf{W} = diag([2.33, 3.45, 4.55, 1, 1.25]), \tag{8}$$

which is determined to include the differences in the joint's strengths [?, ?, ?, ?].

Calculated values for the maximum $\Delta\dot{\mathbf{c}}$ for the five positions are mentioned in Fig. ??. As it can be seen in this figure, the low position has the highest value (i.e. 0.17) for the manipulability and the stance position has the lowest one (i.e. 0.03). Manipulability for the middle and high positions are the same (0.12) and lower than the low position. Also wide stance manipulability (i.e. 0.09) is only better than the stance position. Therefore, according to the manipulability analysis for our models, we expect the same ranking for the five positions in the sense of total average required torque to keep the balance. We will verify this hypothesis in the next subsection.

Results: As already mentioned, inverse dynamics are used to compute the torques that are applied (at the joints) by the human subjects. Joint angles are calculated by using marker positions, and joint velocities and accelerations are estimated by using simple time differentiation. Lengths and inertial parameters of the subjects are calculated via the software that is introduced in [?]. Feather stone's Spatial software package [?] is used for the dynamics calculations.

To work out the average total torque for each position and each perturbation intensity, first we calculate the joint torques from inverse dynamics for each trial (in total 4400 trials $= 5$ poses $\times 8$ intensities $\times 10$ reps $\times 11$ subjects). Then we calculate the average torque over the reps for each joint. Note that, since maximum achievable torque of the arm joints vary with arm configuration, we normalize shoulder and elbow torques for the handle positions [?, ?, ?, ?]. Then, we sum up the normalized joint torques to get 440 (i.e. 5 poses $\times 8$ intensities $\times 11$ subjects) values for the average normalized joint torques. The beginning time is the subjects' average initial reaction time which is estimated by the average EMG signal. The end time is roughly the time that the subjects have recovered from the perturbations.

The means of the normalized joint torques (per subjects) is shown in Fig. ??. This figure shows the total average torque (after removing outliers) for all subjects at each configuration and each intensity. The lines are fitted to the values by using least squares method. The standard error of the means are also shown in this figure. As can be seen in this figure, the low handle pose has the lowest total torque and the stance pose has the highest. According to this graph, the ranking between the positions is 1) low, 2) middle, 3) high, 4) wide stance and 5) stance. This ranking is more visible in higher intensities and it conforms with the manipulability numbers from our analysis. The only difference is that manipulability analysis predicts that middle and high positions are the same whereas experimental results show a bit difference between two (middle is better than high). Therefore, the experimental results agree with the manipulability analysis in the previous subsection. Configurations of greater manipulability require less torque, in order to maintain balance after perturbations of equivalent magnitudes.

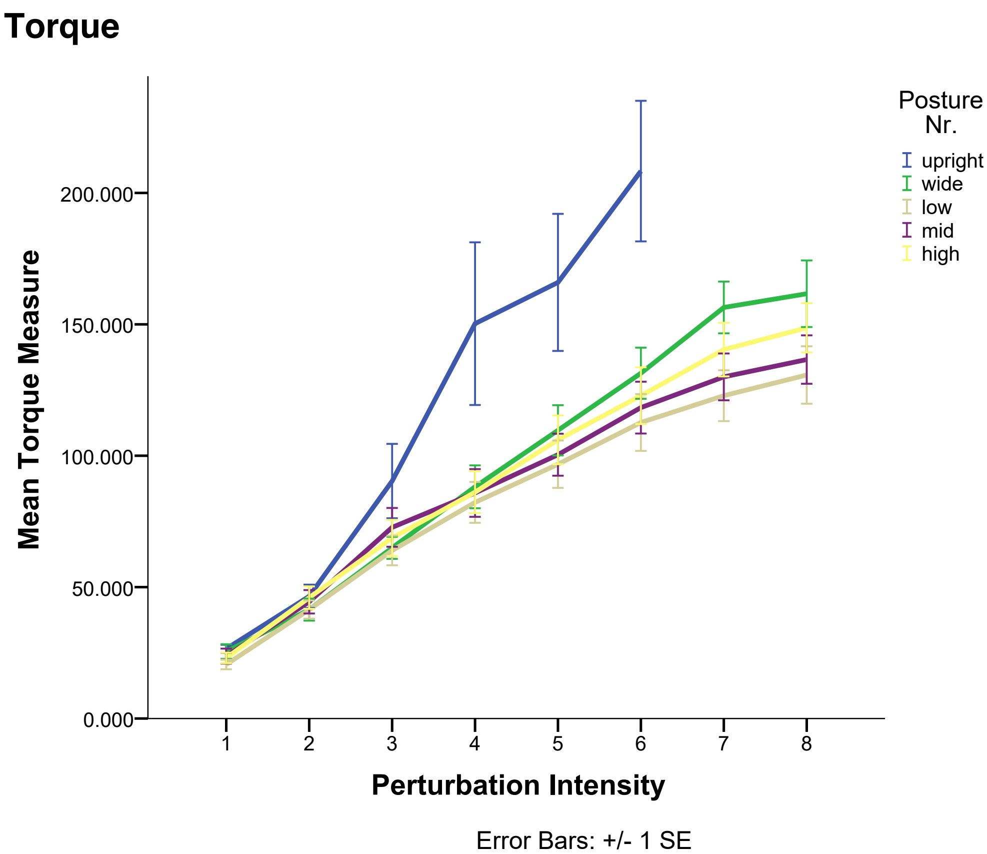


Figure 15: Average of the total torque for the subjects at each pose and each perturbation intensity. The stance position required the most torque in order to maintain balance. While the low handle position required the least amount of torque for the same perturbation.

Conclusion: A set of metrics are introduced in this chapter to study, analyse and measure the ability to balance for humans and robots. These metrics, which are called the manipulability of the center of mass, provide two types of ellipsoids which graphically show how the CoM can be accelerated in 3D space by a certain amount of change of motion (due to impulses) at the joint space. These ellipsoids can be used to measure torque efficiency and maneuverability of humans and robots. The proposed metrics are applicable to floating base robots with non-breakable contacts with the environment. Also, experiments on human subjects are performed to investigate the applicability of the proposed metrics for human studies. In the experiments, the standing subjects (in five different configurations) were perturbed by a controlled force acting on their CoM. Then, the selected configurations were ranked according to the average total torque that is applied by the subjects to recover their balance at each configuration. It is shown that the proposed metric for torque efficiency can successfully predict the same ranking between the configurations as the experimental results suggested. This agreement shows the applicability of the metrics for human studies as well. Therefore, manipulability of the center of mass provides greater insight into the posture controllability of humans and robots, in various configurations and contact conditions.

3.3.2.2.4 Resources Overall, the use of resources within WP2 was in accordance to the plans. There was an increase in the amount of PM for JSI due to the fact that we could not find a suitable Post-doc but hired a PhD student instead. Consequently we foresee approximately 25% increase in total amount of PM at the end of the project.

WP2 person months	**IIT**	**TUD**	**UPMC**	**UB**	**JSI**	**INRIA**
Year 1	0.00	0.00	0.28	2.64	18.80	-
Year 2	0.00	3.00	0.48	7.67	21.85	-
Year 3	0.00	0.00	1.30	NaN	21.69	0.50
Partial	0.00	3.00	2.06	NaN	62.34	0.50
Overall	0.00	4.00	1.00	45.00	55.00	1.00

3.3.2.2.5 Deviations from workplan No significant deviations.

3.3.2.3 Work package 3 progress Summary.

3.3.2.3.1 Result 1 Some result.

3.3.2.3.2 Result 2 Some result.

3.3.2.3.3 Resources

WP3 person months	IIT	TUD	UPMC	UB	JSI	INRIA
Year 1	9.90	4.60	15.15	0.00	0.00	-
Year 2	0.00	10.5	14.67	1.85	1.00	4.00
Year 3	-	9.65	-	-	2.00	-
Partial	9.90	15.10	29.82	1.85	3.00	4.00
Overall	9.00	24.00	43.5	10.00	4.00	10.50

3.3.2.3.4 Deviations from workplan IIT committed own resources to WP3. In particular, Silvio Traversaro significantly contributed to T3.4 with 8PM of work with focus on whole-body parametric identification.

3.3.2.4 Work package 4 progress

Summary.

3.3.2.4.1 Result 1 Some result.

3.3.2.4.2 Result 2 Some result.

3.3.2.4.3 Resources

WP4 person months	IIT	TUD	UPMC	UB	JSI	INRIA
Year 1	0.00	8.00	2.22	0.00	0.00	-
Year 2	6.04	21.70	1.69	2.15	3.00	2.01
Year 3	-	12	-	-	3.00	-
Partial	6.04	41.70	3.91	2.15	6.00	2.01
Overall	30.00	38.00	9.00	12.00	10.00	9.00

3.3.2.4.4 Deviations from workplan TUD substantially underestimated the number of required PMs for the project and already consumed all assigned PMs during the first three years (79.9 PMs were used out of 76 PMs). It appears that 6.75 PMs are needed to complete Task 4.2, Task 4.3 and Task 4.4 in year 4. Due to the temporary problems of hiring a senior researcher in year one, two junior researcher had to fill this gap. Thus, there still exists sufficient budget for TODO:(XXX-2) PMs while TUD aims to contribute 2 PMs from its own endowed funding. In conclusion, this will result in no significant other deviations are reported.

3.3.2.5 Work package 5 progress

Summary.

3.3.2.5.1 Result 1 Some result.

3.3.2.5.2 Result 2 Some result.

3.3.2.5.3 Resources Resources were used with small difference with respect to what planned. In particular IIT invested only 2 PM with respect to 12PM planned. The motivation resides in the fact that WP5 took advantage of the significant effort done in WP1 (software) and WP3 (control) and in a sense resources initially planned on T5.1 eventually have been committed to T1.1, T1.2, T1.3, T3.1 and T3.2.

WP5 person months	IIT	TUD	UPMC	UB	JSI	INRIA
Year 1	2.00	0.00	0.31	0.00	0.00	0.00
Year 2	12.00	0.85	0.05	0.00	0.00	0.00
Partial	14.00	0.85	0.36	0.00	0.00	0.00
Overall	48.00	5.00	2.50	0.00	0.00	1.50

3.3.2.5.4 Deviations from workplan The original work plan was leaving quite a flexible set of possibilities for both the postural task (e.g. sitting on a chair or balancing on the feet) and the goal oriented action (e.g. opening a drawer while standing or manipulating object while sitting). In the final validation scenario it was chosen to consider a interactive scenario, with the torque controlled iCub standing on his feet while trying to grasp an object moved by the experimenter. As soon as the object exceeds the robot workspace, the iCub takes a forward step in order to increase his workspace.

UPMC covered the activities within WP5 with own resources for a total of 0.45 PM. In particular Ryan Lober (PhD student, French PhD research grant) and Darwin Lau (Postdoctoral scholar) participated to the deployment of the whole-body interface developed in WP1 on the iCub robots present at UPMC.

3.3.2.6 Work package 6 progress Activities within work package 6 achieved the expected results both in terms of administrative activities and management activities. As a major achievement, the management successfully concluded a third amendment to include INRIA as a partner. The inclusion was motivated by the the new position of Dr. Serena Ivaldi, currently researcher at INRIA, Nancy.

3.3.2.6.1 Administrative coordination (T6.1) Administration was successfully coordinated by IIT, with significant contribution from Chiara Andreoli (iCub Facility), Francesca Boscolo (project offices) and Maria Carmela Fierro (Robotics, Brain and Cognitive Science Department). The major activity concerned the amendment that the CoDyCo consortium asked the main reason being the fact that Serena Ivaldi, initially hired by UPMC and successively moved to TUD, was recently hired by INRIA as researcher. Part of the administrative coordination activities were also conducted during the mid-year meeting: November 20th-21st, 2014, Ljubljana. Details on the meetings can be found in the CoDyCo website (`http://www.codyco.eu`).

3.3.2.6.2 Software repository implementation (T6.2) The github software repository was several times restructured `https://github.com/robotology/codyco` and the contribution from the different developers can be directly checked in the website.

3.3.2.6.3 Resources

Resources were used as follows.

WP6 person months	IIT	TUD	UPMC	UB	JSI	INRIA
Year 1	1.46	0.00	0.25	0.00	0.10	0.00
Year 2	1.50	0.00	0.31	0.00	0.00	0.00
Year 3	NaN	NaN	NaN	NaN	0.44	NaN
Partial	2.96	0.00	0.56	0.00	0.54	0.00
Overall	5.00	1.00	1.00	0.60	1.00	0.00

3.3.2.6.4 Deviations from workplan

No significant deviations.

3.3.2.7 Work package 7 progress

Dissemination and exploitation activities included the participation to international events addressed to both commercial and academic institutions.

3.3.2.7.1 Dissemination activities towards academia, industry, and other users (T7.1)

Dissemination activities were conducted thorough international publications, organisation of international events, talks at international conferences, press interviews and iCub expositions at international events. Here is the overall contribution subdivided by partner:

- IIT: 4 invited talks, 4 organised international events, 6 talks at international conferences, 10 publications (2 journal, 7 internal conferences, 1 book chapter), 10 media coverage events.
- TUD: 15 invited talks, 4 organised international events, 7 publications (7 internal conferences), 7 media coverage events.
- UPMC: 3 invited talks, 6 publications (6 internal conferences), 1 media coverage event.
- UB: 3 invited talks, 5 publications (5 internal conferences), 5 talks at international conferences.
- JSI: 1 invited talks, 1 organised special issue, 2 talks at international conferences, 7 publications (1 journal, 6 internal conferences).
- INRIA: 4 invited talks, 4 organised international events, 8 publications (4 journal, 4 internal conferences), 3 media coverage events

Live demonstration of the iCub have been performed at several international events. Some of these events were sponsored by CoDyCo and the following is a non exhaustive list:

1. 12^{th}-14^{th} March 2014. EU Robotics Forum Rovereto. `http://www.erf2014.eu/erf_home.jsp`.
2. 3^{rd}-6^{th} June 2014. Automatica 2014, Munich, Germany. `http://www.nfm-automatica.de/2014/en/home.php`.

3. 3^{rd}-5^{th} October 2014. European Maker Faire, Roma, Italy. http://www.makerfairerome.eu/en/agenda2014/.

4. 18^{th}-20^{th} November 2014. 2014 IEEE-RAS International Conference on Humanoid Robots (Humanoids 2014), Madrid, Spain. http://www.humanoids2014.com.

Among the invitations as a speaker at international events it is worth citing the following:

1. Francesco Nori: invited speaker at the Journes Nationales du GdR Robotique 2014, held at Grand amphithéâtre du Centre Arts et Mètiers ParisTech, 151-155 boulevard de l'Hpital, 75013 Paris. 30 October 2014. http://www.gdr-rob2014.org.

2. Serena Ivaldi: invited speaker French-German-Japan Workshop on Humanoid and Legged robots. Social learning and engagement in human-humanoid interactions. http://orb.iwr.uni-heidelberg.de/hlr2014/HLR14.

3. Jan Babic: invited talk in Paris at the Universit Pierre et Marie Curie. Synthesis of skilled robotic behaviour through human sensorimotor adaptation: 12^th November 2014.

4. Jan Peters: keynote for the Learning by Demonstration Session Topic at the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Chicago, USA.

5. Jan Peters: invited plenary talk speaker at the 13th International Conference on Intelligent Autonomous Systems (IAS-13), Padua, Italy.

6. Vincent Padois: invited talk at the Cap Digital/Innorobo day about Robotics et Innovations. "Issues and challenges of interactive robotics in complex industrial contexts". Lyon, France - March 2014.

7. Michael Mistry: invited Lecturer at European Computational Motor Control Summer School. June 15^th-21^st, 2014.

Among the organised international events here is a non exhaustive list of the most relevant events:

1. IIT: workshop organisation at the 2014 IEEE-RAS international conference on humanoid robots (Humanoids 2014). ?One day with a humanoid robot: a crash course on the iCub software tools?. Coordinators: L. Natale, F.Nori, U. Pattacini, V. Tikhanoff, M. Randazzo, G. Metta (Italy).

2. IIT: iCub summer school (Veni Vidi Vici 2014). In 2014, the school was held in Sestri Levante, Italy, July 21-30 2014. Main organisers: Giorgio Metta, Lorenzo Natale, Francesco Nori, Vadim Tikhanoff, Ugo Pattacini.

3. INRIA, TUD, UB, JSI: editors for the Autonomous Robots special Issue: "Whole-body control of contacts and dynamics for humanoid robots".

3.3.2.7.2 Exploitation plan (T7.2) The third year activities on T7.1 and T7.2 are all contained in "D7.1 Dissemination and exploitation plan" available here: https://github.com/robotology-playground/codyco-deliverables/tree/master/D7.1/pdf.

3.3.2.7.3 Management of IPR (T7.3) No activities to be reported during the third year on this task in consideration of the fact that the task started at the very end of the third year. As a minor starting activity the consortium circulated a list containing each partner responsible contact person for the IPR management. This list is contained in "D7.1 Dissemination and exploitation plan" available here: `https://github.com/robotology-playground/codyco-deliverables/tree/master/D7.1/pdf`.

3.3.2.7.4 Dissemination of a database of human motion with contacts (T7.4) During the third year of CoDyCo, IIT completed the task of setting up a database for storing both human and robot datasets. The details on the database are reported in "D7.2 Standard database with support materials" available here `https://github.com/robotology-playground/codyco-deliverables/tree/master/D7.2/pdf`.

3.3.2.7.5 Resources Resources were used as follows.

WP7 person months	IIT	TUD	UPMC	UB	JSI	INRIA
Year 1	1.00	0.00	0.40	0.00	0.00	-
Year 2	0.00	0.00	0.13	0.00	0.00	0.91
Partial	1.00	0.00	0.53	0.00	0.00	0.91
Overall	3.00	1.00	1.00	1.00	1.00	1.00

3.3.2.7.6 Deviations from workplan No significant deviations.

3.4 Deliverables and milestones tables

3.4.1 Deliverables (excluding the periodic and final reports)

3.4.2 Milestones

Del. no.	Deliverable name	WP	Type	Date	Respon sible	Person Month
D1.2	Software for controlling of balancing and reaching with multiple contacts.	1	SW	M24	UB	16
D3.1	Local solver in rigid-world cases.	3	R	M24	UPMC	18
D4.2	Learning of tasks with multiple contacts by imitation and reinforcement learning.	4	R	M24	TUD	30
D5.2	Validation scenario2: balancing on feet while performing goal directed actions.	5	R	M24	IIT	13

R = Report, **P** = Prototype, **D** = Demonstrator, **SW** = Software, **O** = Other

Milestone number	Milestone name	Work package(s) involved	Expected date [1]	Leader	Means of verification
MS.2	Validation scenario2: balancing on feet while performing goal directed actions	MS.1 T1.3 T1.5 T4.3 T5.2	M24	IIT	- The iCub successfully reaches an object while exploiting multiple contacts

A List of dissemination events

A.1 IIT contributions to dissemination

4 invited talks, 4 organised international events, 6 talks at international conferences, 10 publications (2 journal, 7 internal conferences, 1 book chapter), 10 media coverage events, 11 iCub demos at dissemination events.

A.1.1 Invited talks

1. Invited speaker at the international workshop on Whole-Body Control for Robots in the Real World, held at the 2014 IEEE/RSJ international conference on intelligent robots and systems (IROS 2014). Contribution presented by Silvio Traversaro.

2. Invited speaker at the ?Cognitive Humanoid Robotics Research? workshop, held within the 2014 IEEE-RAS international conference on humanoid robots (Humanoids 2014). November 17th, 2014

3. Invited speaker at the Journes Nationales du GdR Robotique 2014, held at Grand amphithtre du Centre Arts et Mtiers ParisTech, 151-155 boulevard de l'Hpital, 75013 Paris. 30 October 2014.

4. Invited speaker at the first KoroiBot Summer School, held in Heidelberg from September 22nd to September 26th 2014.

A.1.2 International events organisation

Summary: 1) iCub Summer School 2) IROS 2015 event 3) Ballar 4) Creative Mornings 5) RSS workshop 6) Festival della Scienza

- CISCO conference Milano 26/1 - CISCO conference Milano 28/1 - Geo & Geo Roma 25/2 - Lancio cartone Transformers 1/3 - ERF Vienna, workshop on humanoids in the laboratory (chimica, ecc.) 12/3 - Conferenza stampa De Agostini (lancio X-makers) Barcellona 26/3 - ITURO conference Istanbul, keynote 11/4 - CSIFT Shanghai, investors presentation 22-24/4 - Bal Robotov, invited forum on robotics, Mosca 29/4 - Robobusiness, invited, Milan 30/4 - Summer school on Sensing, Lille 21/5 - Boston Woodshole, summer school CBMM, Robotics Afternoon, 18-22/8 - Sky International, TV, 25/8 - Uno Mattina, Rai1, 1/9 - Rai Petrolio, 10/9 - Expo, Padiglione Italia, 15/9 - Aimeta conference, keynote, Genova, 16/9 - Researchers night, invited, LAquila 26/9 - Trieste Next Fest, invited, Trieste 27/9 - IROS, Hamburg 28/9, 2/10 - Caidate scientific talks, Caidate, 3/10 - Space Challenge, keynote/lecture, Sofia, 6/10

1. The iCub Summer School, "Veni Vidi Vici", serves to consolidate and disseminate skills in software engineering for humanoid robots. Our goal is to foster collaboration on robot software across the boundaries and lifetimes of specific platforms and projects. The school focuses on humanoid robotics and will host at least two iCub and a COMAN robot. Students will receive an initial training on the software infrastructure (middleware and tools) and will be required to work on a project of their choice. All participants are

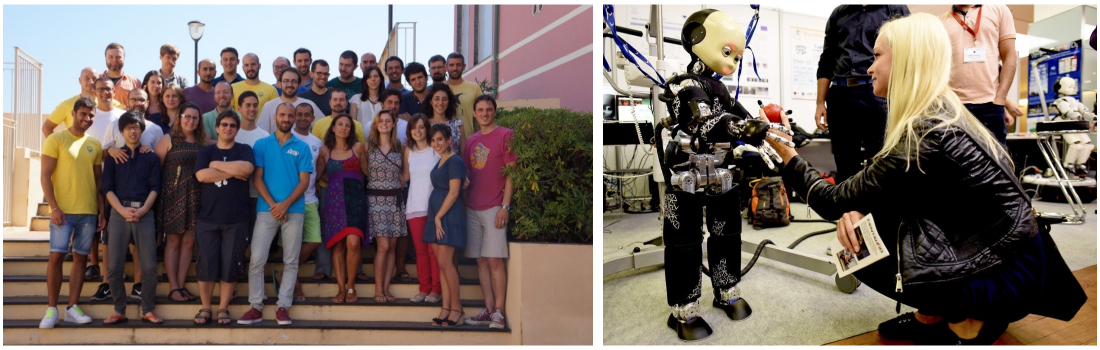


Figure 16: Left: the iCub Veni-Vidi-Vici summer school. Right: the iCub at the IROS 2015 event organised by the robotics unit at the European Commission.

expected to be competent C/C++ programmers with an interest in working with others (and an agenda of their own). Info: `http://wiki.icub.org/wiki/VVV15`

2. During the IROS 2015 International Conference at Hamburg, different versions of iCub (the Genova Black, and the Heidelberg version) were shown in an exhibition. For three days, iCub interact with visiting people performing different demos, such as torque balancing and the red ball demo. Photo by Fabian Bimmer/Reuters)

3. iCub has been a special guest in Ballaró, an italian political show on the public television network.

4. In May, Francesco Nori was an invited speaker at the Creative Mornings event. The talk gave historical and philosophical motivations that guided recent research activities towards the problem of studying how humans interact with the environment and among themselves. The iCub was also presented, as an open-source platform capable of advancing the state-of-the-art in various directions, e.g. decisional autonomy, dependability/adaptability, perception and, in a single all-embracing word, cognitive abilities.

5. In July, during the RSS conference in Rome, a full day workshop titled ?Towards a Unifying Framework for Whole-body and Manipulation Control? has been organised. Topics covered the following areas:

   - Contacts planning and control
   - Whole-body task control
   - Compliant whole-body movements
   - Dynamics in humanoid robots
   - Machine learning and optimization methods for contact planning and control

6. From 22nd of October to 1st of November 2015, the iCub will be showed at the "Festival della Scienz". Festival della Scienza, now at its 13th edition, is a publicly opened event which focus on science. During this festival, temporary laboratories and exhibition booths are prepared where researchers and scientists can show and explain to people their work.

Presentations are targeted to different audiences, from children to university students to adults. This year festival theme is ?Equilibrium?, and iCub will perform daily showing balancing demos.

A.1.3 Talks at international conferences

1. Talk by Francesco Nori. A. Del Prete, F. Romano, L. Natale, G. Metta, G. Sandini and F. Nori. Prioritized Optimal Control. 2014 IEEE International Conference on International Conference on Robotics and Automation (ICRA 2014).

2. Talk by Francesco Romano. Romano F., Fiorio L., Sandini G. and Nori F. 2014, ?Control of a two-DOF manipulator equipped with a pnr- Variable Stiffness Actuator?, 2014 IEEE Multi-Conference on Systems and Control, Antibes, France, October 8-10, 2014.

3. Talk by Luca Fiorio. Fiorio L., Romano F., Parmiggiani A., Sandini G. and Nori F. 2014, ?Stiction Compensation in Agonist-Antagonist Variable Stiffness Actuators?, 2014 Robotics: Science and Systems Conference, Berkeley, California, USA, July 12-16, 2014.

4. Talk by Serena Ivaldi. Ivaldi S., Peters J., Padois V. and Nori F. 2014, ?Tools for simulating humanoid robot dynamics: a survey based on user feedback?, Proceedings of the International Conference on Humanoid Robots (HUMANOIDS 2014)., Madrid, Spain, November 18-20, 2014, Spain.

5. Talk by Serena Ivaldi. Nori F., Peters J., Padois V., Babic J., Mistry M. and Ivaldi S. 2014, ?Whole-body motion in humans and humanoids?, Proceedings of the Workshop on New Research Frontiers for Intelligent Autonomous Systems (NRF-IAS).

6. Talk by Carlo Ciliberto. Ciliberto C., Fiorio L., Maggiali M., Natale L., Rosasco L., Metta G., Sandini G. and Nori F. 2014, ?Exploiting global force torque measurements for local compliance estimation in tactile arrays?, IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2014), Chicago, USA, September 14-18, 2014.

A.1.4 Pubblications

Del Prete A., Nori F., Metta G. and Natale L. 2015, ?Prioritized motionforce control of constrained fully-actuated robots: Task Space Inverse Dynamics?, Robotics and Autonomous Systems, vol. 63,no. 1, pp. 150?157.

F Nori, S Traversaro, E Jorhabib, F Romano and D Del Prete A.; Pucci. iCub Whole-body Control through Force Regulation on Rigid Noncoplanar Contacts. Frontiers in Robotics and AI.

H E Mingo, S Traversaro, R Alessio, F Mirko, A Settimi, F Romano, L Natale, A Bicchi, F Nori and G Tsagarakis. A Yarp based plugin for Gazebo Simulator. In Modelling and Simulation for Autonomous Systems. 2014

Ciliberto C., Fiorio L., Maggiali M., Natale L., Rosasco L., Metta G., Sandini G. and Nori F. 2014, ?Exploiting global force torque measurements for local compliance estimation in tactile arrays?, IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2014), Chicago, USA, September 14-18, 2014.

Del Prete A., Romano F., Natale L., Metta G., Sandini G. and Nori F. 2014, ?Prioritized Optimal Control?, IEEE International Conference on Robotics and Automation (ICRA2014), IEEE, Hong Kong, China, May 31-June 7, 2014, 2014.

Del Prete A., Mansard N., Nori F., Metta G. and Natale L. 2014, ?Partial Force Control of Constrained Floating-Base Robots?, IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2014), Chicago, Illinois, September 1418, 2014.

Fiorio L., Romano F., Parmiggiani A., Sandini G. and Nori F. 2014, ?Stiction Compensation in Agonist-Antagonist Variable Stiffness Actuators?, 2014 Robotics: Science and Systems Conference, Berkeley, California, USA, July 12-16, 2014.

Ivaldi S., Peters J., Padois V. and Nori F. 2014, ?Tools for simulating humanoid robot dynamics: a survey based on user feedback?, Proceedings of the International Conference on Humanoid Robots (HUMANOIDS 2014)., Madrid, Spain, November 18-20, 2014, Spain.

Mingo H.E., Traversaro S., Alessio R., Mirko F., Settimi A., Romano F., Natale L., Bicchi A., Nori F. and Tsagarakis G. Nikos 2014, ?A Yarp based plugin for Gazebo Simulator?, 2014 Modelling and Simulation for Autonomous Systems,.

Nori F., Peters J., Padois V., Babic J., Mistry M. and Ivaldi S. 2014, ?Whole-body motion in humans and humanoids?, Proceedings of the Workshop on New Research Frontiers for Intelligent Autonomous Systems (NRF-IAS),.

Romano F., Fiorio L., Sandini G. and Nori F. 2014, ?Control of a two-DOF manipulator equipped with a pnr- Variable Stiffness Actuator?, 2014 IEEE Multi-Conference on Systems and Control, Antibes, France, October 8-10, 2014.

A.1.5 Media coverage

- http://video.repubblica.it/edizione/genova/genova-icub-il-robot-bambino-ora-sta-in-piedi/167466/165953
- http://www.nextme.it/tecnologia/robotica/8958-icub-robot-morbidi-8-anni-video
- http://video2k.is/index.php/videos/v/jaTEbCsFp_M/yt
- http://meta-guide.com/videography/100-best-icub-robot-videos/
- http://www.33rdsquare.com/2015/02/icub-becomes-master-of-balancing.html
- http://video.corriere.it/robot-icub-fa-progressi-equilibrio/a20154ce-c961-11e4-84dd-480351105d62
- http://www.geniuslab.org/storie/con-il-raggiungimento-dellequilibrio-icub-accorcia-i-tempi-per-entrare-nelle-nostre-case/
- http://www.rainews.it/dl/rainews/media/Occhi-grandi-e-sorrisone-il-cucciolo-robot-muove-i-primi-passi-93898c5e-032b-4f2f-9240-14ee1682e87c.html
- https://www.youtube.com/watch?v=jtjBsBE5GIIandt=3m36s

- http://www.rai.tv/dl/RaiTV/programmi/media/ContentItem-38aee841-5df8-48e2-ba54-064c0457bc45.html#p=0

A.1.6 iCub at international events

1. Innovation Convention 2014 Brussels
2. European Robotics Forum Rovereto
3. Innorobo 2014 Lyon
4. World Science Festival New York City
5. Automatica 2014 Munich
6. Festival della Comunicazione Camogli
7. European Maker Faire Roma
8. RAI Studios [i Fatti Vostri] Roma
9. Humanoids 2014 Madrid
10. RAI Studios [Rai2Next] Roma
11. Embedded Technology 2014 Tokyo

A.2 TUD contributions to dissemination

15 invited talks, 4 organised international events, 7 publications (7 internal conferences), 7 media coverage events

A.2.1 Invited talks

1. 16 Oct 2015 University College London, London, UK, host: Guy Lever.
2. 14 Oct 2015 University of Oxford, Oxford, UK, host: Michael Osborne, Machine Learning Research Group.
3. 13 Oct 2015 Imperial College London, London, UK, host: Stefan Leutenegger, Dyson Robotics Lab.
4. 03 Jun 2015 University of British Columbia, Vancouver, Canada, host: Mark Schmidt.
5. 02 Jun 2015 University of Washington, Seattle, US, host: Dieter Fox, Robotics and State Estimation Lab.
6. 01 Apr 2015 TU Freiburg, Freiburg, Germany, host: Frank Hutter.

7. 11/2015 Understanding Human Motor Control through Robotics Applications. Invited Talk in Prof. Constantin Rothkopfs seminar on research and applications of psychology in IT, Darmstadt, Germany.

8. 02/2015 Probabilistic Inference and Modeling of Human Motor Skill Learning. Invited Talk. Workshop with Marc Toussaints group, Wolfram Burgards group and Oliver Brocks group, Manigod, France.

9. 06/2015 Universität Ulm, Host: F. Kargl, Ulm, Germany, July, 2015.

A.2.2 Publications

1. E Rueckert, D Kappel, D Tanneberg, D Pecevski and J Peters. Recurrent Spiking Networks Solve Planning Tasks. Scientific Reports, Nature Publishing Group, 2016.

2. R Calandra, A Seyfarth, J Peters and M P Deisenroth. Bayesian optimization for learning gaits under uncertainty. Annals of Mathematics and Artificial Intelligence, pages 119, 2015.

3. J Kohlschuetter, J Peters and E Rueckert. Learning Probabilistic Features from EMG Data for Predicting Knee Abnormalities. In Proceedings of the XIV Mediterranean Conference on Medical and Biological Engineering and Computing (MEDICON), 2016.

4. V Modugno, G Neumann, E Rueckert, G Oriolo, J Peters and S Ivaldi. Learning soft task priorities for control of redundant robots. In Proceedings of the International Conference on Robotics and Automation (ICRA), 2016.

5. R Calandra, S Ivaldi, M Deisenroth, E Rueckert and J Peters. Learning Inverse Dynamics Models with Contacts. In Proceedings of the International Conference on Robotics and Automation (ICRA). 2015.

6. R. Calandra, S. Ivaldi, Marc. P. Deisenroth, E. Rueckert, and J. Peters. Learning inverse dynamics models with contacts using tactile sensors. ICRA 2015 Workshop on Tactile & force sensing for autonomous, compliant, intelligent robots, 2015.

7. E Rueckert, J Mundo, A Paraschos, J Peters and G Neumann. Extracting Low-Dimensional Control Variables for Movement Primitives. In Proceedings of the International Conference on Robotics and Automation (ICRA). 2015.

8. S Traversaro, A Del Prete, S Ivaldi and F Nori. Avoiding to rely on Inertial Parameters in Estimating Joint Torques with proximal F/T sensing. In Proceedings of the International Conference on Robotics and Automation (ICRA). 2015.

9. A Paraschos, E Rueckert, J Peters and G Neumann. Model-free Probabilistic Movement Primitives for physical interaction. In Intelligent Robots and Systems (IROS), 2015 IEEE/RSJ International Conference on. 2015, 28602866.

10. E Rueckert, R Lioutikov, R Calandra, M Schmidt, P Beckerle and J Peters. Low-cost Sensor Glove with Force Feedback for Learning from Demonstrations using Probabilistic Trajectory Representations. In ICRA 2015 Workshop on Tactile and force sensing for autonomous compliant intelligent robots. 2015.

11. L Fritsche, F Unverzag, J Peters and R Calandra. First-person tele-operation of a humanoid robot. In Humanoid Robots (Humanoids), 2015 IEEE-RAS 15th International Conference on. 2015, 9971002.

12. R Calandra, S Ivaldi, M P Deisenroth and J Peters. Learning torque control in presence of contacts using tactile sensing from robot skin. In Humanoid Robots (Humanoids), 2015 IEEE-RAS 15th International Conference on. 2015, 690695.

A.2.3 Media coverage

1. 09/2015 Kinderuni Darmstadt. Interactive robot demonstrations of the Nao, the ICub and the Darias robots. Supported by Veronika Weber and Guilherme J. Maeda.

2. 04/2015 Major German TV program, SAT1. Life demonstrations of teaching the ICub how to stack cup.

3. 03/2015 KID Science Radioclub. Lab tour and life demonstrations of the Oncilla, the ICub and the Darias robots. Supported by Veronika Weber, Guilherme J. Maeda, Rudolf Lioutikov and Roberto Calandra.

A.2.4 MSc. and Ph.D. theses

1. Stark S. MSc. thesis. Learning Probabilistic Feedforward and Feedback Policies for Generating Stable Walking Behaviors. 2016.

2. Kohlschuetter J. MSc. thesis. Learning Probabilistic Classifiers from Electromyography Data for Predicting Knee Abnormalities. 2016.

3. D Tanneberg. MSc. thesis. Spiking Neural Networks Solve Robot Planning Problems. 2016.

4. O Kroemer. Machine Learning for Robot Grasping and Manipulation. 2015.

A.3 Student research stays

1. E Rueckert, 2014. Jozef Stefan Institute, Slovenia, Department of Automation, Biocybernetics and Robotics, Prof. Dr. Jan Babic. Research internship on investigating the functional role of supportive contacts in human postural control.

A.4 Organised conference workshops

1. R. Calandra: Organizer of the Workshop on Bayesian Optimization (BayesOpt) at NIPS 2015. Web: http://bayesopt.github.io/

A.5 Meetings with industrial partners

A.6 Invited speakers

1. W. Kellermann, Invited Speaker at TUDA, *Friedrich-Alexander Univerisität Erlangen-Nürnberg*, Erlangen, Germany, December, 2015.

2. D. Nikolic, Invited Speaker at TUDA, *Max-Planck Institut for Brain Research*, Frankfurt, Germany, January, 2016.

3. V. Lippi, Invited Speaker at TUDA, *Uniklinik Freiburg*, Freiburg, Germany, February, 2016.

4. F. Hutter, Invited Speaker at TUDA, *Universität Freiburg*, Freiburg, Germany, February, 2016.

A.7 Collaborations

1. UB and TUD, involved are M. Azad, M. Mistry, J. Peters, E. Rueckert. Title: *Uncertainty in contact*, first results on TUD's ICub. Paper submission planned for a robotics conference (HUMANOIDS, ICRA) in 2016.

2. TUD and JSI, involved are J. Babic, J. Camernik, J. Peters, E. Rueckert. Title: *Postural control predicts volitional motor control*, paper submitted for review at Scientific Reports, 01/2016.

A.8 UPMC contributions to dissemination

3 invited talks, 0 organised international events, 6 publications (6 internal conferences), 1 media coverage events

A.8.1 Invited talks

1. Aurlien Ibanez, Vincent Padois, Philippe Bidaud - "Whole-body control of humanoid robots and virtual humans at ISIR: Multi-objective activities, locomotion and Model Predictive Control" - Invited talk at the French-German-Japanese Conference on Humanoid and Legged Robotics (HLR) - Heidelberg, Germany - May 2014.

2. Olivier Sigaud - "Towards robots immersed in our society: where are we now?" - Invited talk at the cognitive science student society of Marseille" - Marseille, France - March 2015.

3. Vincent Padois - ?Issues and challenges of interactive robotics in complex industrial contexts". Invited talk at the Cap Digital/Innorobo day about ?Robotics et Innovations?, Lyon, France - March 2014.

A.8.2 Publications

R Lober, V Padois and O Sigaud. Multiple Task Optimization using Dynamical Movement Primitives for Whole-Body Reactive Control. In Proceedings of the IEEE-RAS International Conference on Humanoid Robots (Humanoids). 2014

M Liu, S Hak and V Padois. Generalized Projector for Task Priority Transitions During Hierarchical Control. In Proceedings of the IEEE International Conference on Robotics and Automation. 2015.

S Ivaldi, J Peters, V Padois and F Nori. Tools for simulating humanoid robot dynamics: a survey based on user feedback. In Proceedings of the IEEE-RAS International Conference on Humanoid Robots (Humanoids). November 2014.

Aurlien Ibanez, Philippe Bidaud and Vincent Padois. Automatic optimal biped walking as a Mixed-Integer Quadratic Program. In J Lenarčič and O Khatib (eds.). Advances in Robot Kinematics. Springer International Publishing, 2014, pages 505-516. DOI BibTeX

Aurlien Ibanez, Philippe Bidaud and Vincent Padois. Emergence of humanoid walking behaviors from Mixed-Integer Model Predictive Control. In Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems. 2014. DOI BibTeX

Aurlien Ibanez, Philippe Bidaud and Vincent Padois. A Distributed Model Predictive Control approach for robust postural stability of a humanoid robot. In Proceedings of the IEEE International Conference on Robotics and Automation. June 2014. BibTeX

Aurlien Ibanez, Philippe Bidaud and Vincent Padois. Automatic optimal biped walking as a Mixed-Integer Quadratic Program. In Proceedings of the 14th International Symposium on Advances in Robot Kinematics. July 2014. BibTeX

A.8.3 Media coverage

Olivier Sigaud - "Robolution" - Documentary by V. Gonon and X. Sayanoff for the "Cine + Frisson" - December 2014.

A.9 UB contributions to dissemination

3 invited talks, 0 organised international events, 5 publications (5 internal conferences), 0 media coverage events

A.9.1 Invited talks

1. Invited Talk at Human Motion Modeling and Human Inspired Motor Control Workshop, Humanoids 2014
2. Invited Lecturer at European Computational Motor Control Summer School, 6/2014
3. Invited Talk at Honda Research Europe, 6/2014

A.9.2 Publications

M Azad, M Mistry, Balance Control Strategy for a Robot with Compliant Contacts, Int. Conf on Robotics and Automation, 2015.

NT Alberto, M Mistry, F Stulp, Computed Torque Control with Variable Gains through Gaussian Process Regression, Int. Conf. on Humanoid Robotics, 2014.

M Azad, J Babic, M Mistry, Effects of Hand Contact on the Stability of a Planar Humanoid with a Momentum Based Controller, Int. Conf. on Humanoid Robotics, 2014.

V Ortenzi, M Adjigble, K Jeffery, R Stolkin, M Mistry, An experimental study of robot control during environmental contacts based on projected operational space dynamics, Int. Conf. on Humanoid Robotics, 2014.

M. Azad and R. Featherstone, Balancing control algorithm for a 3D under-actuated robot, Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems, Chicago, Illinois, 14-18 September 2014.

A.10 JSI contributions to dissemination

2 invited talks, 1 editorial for journal special issue, 3 publications (2 journal, 1 internal conferences), 0 media coverage events.

A.10.1 Invited talks

1. Babic, Jan. Human-in-the-loop control of robots for industrial assembly tasks : invited talk, Omron Keihanna Technology Innovation Center, 7th September 2015, Kyoto, Japan.

2. Babic, Jan. Compliant robotic behaviour through human sensorimotor adaptation : presented at ICRA 2015, IEEE International Conference on Robotics and Automation, May 26th-30th, 2015, Seattle, Washington, USA.

A.10.2 Editorial work

1. Babic, J. Guest editor of Autonomous robots, Kluwer Academic Publishers, 1994-. ISSN 0929-5593. http://link.springer.com/journal/10514.

A.10.3 Publications

Ivaldi, S., Babic, J., Mistry, M., Murphy, R. Special issue on whole-body control of contacts and dynamics for humanoid robots. Autonomous robots, 2016, vol. 40, no. 3, 425-428.

Peternel, L., Noda, T., Petric, T., Ude, A,. Morimoto, J., Babic, J. Adaptive control of exoskeleton robots for periodic assistive behaviours based on EMG feedback minimisation. PloS one, ISSN 1932-6203, 2016, vol. 11, no. 2, 0148942-1-0148942-26.

Peternel, L., Petric, T., Babic, J. Human-in-the-loop approach for teaching robot assembly tasks using impedance control interface. In: 2015 IEEE International Conference on Robotics and Automation, May 26th-30th, 2015, Seattle, Washington, USA. ICRA 2015. Danvers: IEEE = Institute of Electrical and Electronics Engineers, cop. 2015, 1497-1502.

A.11 INRIA contributions to dissemination

4 invited talks, 4 organised international events, 8 publications (4 journal, 4 internal conferences), 3 media coverage events

A.11.1 Invited talks

1. Ivaldi, S. (2014) iCub interacting with humans: software tools and best practices. Invited talk at IEEE Humanoids 2014 Workshop - One day with a humanoid robot.

2. Ivaldi, S. (2014) Social learning and engagement in human-humanoid interactions. Invited talk at IAS13 Workshop on Evaluating social robots.

3. Ivaldi, S. (2014) Humanoids and dynamics estimation and simulation. Invited talk at French-German-Japan Workshop on Humanoid and Legged robots.

4. Ivaldi, S. (2014) iCub learning from humans via multimodal, physical, social and natural interaction: experiments from MACSi, EDHHI and CODYCO projects. Invited talk at IEEE ICRA 2014 Workshop - iCub and friends.

A.11.2 Organised workshop/special sessions

1. ICRA 2015: organizer of Workshop "Tactile and force sensing for autonomous, compliant and intelligent robots?. Web: http://www.ausy.tu-darmstadt.de/Workshops/ICRA2015TactileForce

2. ICRA 2015: member of the Program Committee of the Workshop "Compliant and Versatile Robot Control in Human Environments: Bridging the Gap between Learning and Control?. Web: http://cs.stanford.edu/people/khansari/ICRA2015/index.html

3. 2014: Preliminary results of project EDHHI: where do people gaze and touch during HRI? Invited talk at Journe LABEX SeNSE by Catherine Achard

4. 2014: Robot learning through interaction with humans Invited talk at Telecom-ParisTech by Catherine Pelachaud

A.11.3 Media coverage

1. March 2015, interview at Radio 24 in the program ?Giovani Talenti?: http://www2.radio24.ilsole24ore.com/blog/nava/2015/03/14/ricercatrice-di-robotica-in-francia/

2. September 2014, article on ?Le point? (french newspaper) `http://www.lepoint.fr/villes/l-appartement-de-demain-15-09-2014-1863287_27.php`

3. April 2014, article and comics on the blog L?Avventura on The Monde (french national newspaper) `http://lavventura.blog.lemonde.fr/2014/04/07/qui-a-peur-du-robot-google/`

A.11.4 Publications

Anzalone, S.; Boucenna, S.; Ivaldi, S.; Chetouani, M. (2015) Evaluating the engagement with social robots. International Journal of Social Robotics. In press.

Droniou, A.; Ivaldi, S.; Sigaud, O. (2014) Deep unsupervised network for multimodal perception, representation and classification. Robotics and Autonomous Systems.

Saut, J.-P.; Ivaldi, S.; Sahbani, A.; Bidaud, P. (2014) Grasping objects localized from uncertain point cloud data. Robotics and Autonomous Systems, vol 62, n. 12, pp.1742?1754.

Ivaldi, S.; Anzalone, S.M.; Rousseau, W.; Sigaud, O.; Chetouani, M. (2014) Robot initiative in team learning task increases the rhythm of interaction but not the perceived engagement. Frontiers in Neurorobotics. Vol 8, No 5, DOI 10.3389/fnbot.2014.00005.

Calandra, R.; Ivaldi, S.; Deisenroth, M.P.; Rueckert, E.; Peters, J. (2015). Learning Inverse Dynamics Models with Contacts, Proc. IEEE International Conference on Robotics and Automation (ICRA).

Traversaro, S.; Del Prete, A.; Ivaldi, S.; Nori, F. (2015). Avoiding to rely on Inertial Parameters in Estimating Joint Torques with proximal F/T sensing, Proc. IEEE International Conference on Robotics and Automation (ICRA).

Ivaldi, S.; Peters, J.; Padois, V.; Nori, F. (2014). Tools for simulating humanoid robot dynamics: a survey based on user feedback, Proceedings of the International Conference on Humanoid Robots (HUMANOIDS).

Droniou, A.; Ivaldi, S.; Sigaud, O. (2014). Learning a repertoire of actions with Deep Neural Networks, Proceedings of the Int. Conf. on Development and Learning (ICDL).

Nori, F.; Peters, J.; Padois, V.; Babic, J.; Mistry, M.; Ivaldi, S. (2014) Whole-body Motion in Humans and Humanoids. Workshop New Research Frontiers for Intelligent Autonomous Systems ? NRF-IAS-2014. Invited paper.