FP7-600716

Whole-Body Compliant Dynamical Contacts in Cognitive Humanoids

Year 4

Fourth 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, iCub is a peculiar platform being the only humanoid integrating whole-body distributed force and tactile sensors. In this sense CoDyCo fourth year specific objectives were to design and implement the control of whole-body posture during physical human robot interaction. Other long term objectives involve setting up the necessary infrastructure (human experimental protocols, software infrastructure, learning and control specifications) for leveraging the activities in previous years.

Task	IIT	TUD	UPMC	UB	JSI	INRIA	
WP1	0.00	1.00	-	2.18	2.00	2.96	8.14
WP2	-	3	1.20	13.88	21.69	0.52	38.29
WP3	-	3.6	8.79	1.63	2.00	4.03	26.10
WP4	9.79	4	0.74	1.68	3.00	3.30	30.51
WP5	13.06	2	0.14	1.44	-	0.52	17.16
WP6	1.51	0	0.19	-	0.44	-	3.14
WP7	1.00	1	0.11	-	-	-	1.11
	25.36	14.6	11.17	20.81	29.13	11.33	**123.45**

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. Since all the deliverables of WP1 were delivered by the end of the third year, the main goal of this WP in the fourth year was to improve the software and enhance the iDyn Library.

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

- The overall goal of this work package is to ...
- The expected outcomes for year 1 were ...

3.2.1.3 WP3: control and optimization of whole-body motion in contact (UPMC)

- The overall goal of this work package is to ...
- The expected outcomes for year 1 were ...

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 fourth year objectives of WP4 include:

- 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 fourth year main objective for WP5 was the implementation of a validation scenario consisting of the assisted standing up motion.

3.2.1.6 WP6: management (IIT) The fourth year management was primarily dedicated to the project concluding activities.

3.2.1.7 WP7: dissemination and Exploitation (IIT) The main dissemination objectives for the CoDyCo fourth year were the publication of scientific papers and videos.

3.3 Work progress and achievements during the period

3.3.1 Progress overview and contribution to the research field

All the CoDyCo fourth year objectives have been attained. Here is a list of the CoDyCo fourth 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 fourth year. In summary, the main accomplishments and impacts for the research community are as follows:

- In T1.3. IIT worked on enhancing the wholeBodyInterface.
- In T1.5. IIT implemented BERDY C++ and sparse matrix representation.
- In T1.3. UPMC kept on improving OCRA.
- In T1.5. INRIA developed different modules for visualization of torques, interfacing a haptic device and learning movement primitives.

WP2: understanding and modelling human whole-body behaviours in physical interaction (JSI) After the fourth year of project, WP2 objectives were achieved for the fourth year. In summary, the main accomplishments and impacts for the research community are as follows:

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WP3: control and optimization of whole-body motion in contact (UPMC) After the fourth year of project, WP3 objectives were achieved for the fourth year. In summary, the main accomplishments and impacts for the research community are as follows:

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WP4: adaptation, generalization and improvement of compliant control and tasks with contacts (TUD) After the fourth year of project, WP4 objectives were achieved for the fourth year. In summary, the main accomplishments and impacts for the research community are as follows:

- Based on the probabilistic movement representation of skills we developed a novel approach for learning task prioritizations from human demonstrations. Our approach follows the concept of "soft" priorities, where a task which is lower in the task-hierarchy can controllably interfere with a higher-priority task.
- We investigated how to generate whole-body "safe" motions, by optimizing the profile of task priorities with respect to a given fitness function under several strict constraints. We studied different black-box stochastic search algorithms to optimize the task priorities in a way that guarantees that constraints are never violated.

WP5: systems integration, standardization and evaluation on the iCub robot (IIT) The fourth year WP5 activities have concentrated on the fourth year validation scenario. A complete description of the scenario can be found in "D5.4 Validation scenario 4: learning how to stand up with the help of a human caregiver.." which discusses the technical implementation of the fourth year validation scenario (see `https://github.com/robotology-playground/codyco-deliverables/tree/master/D5.4/pdf`). With respect to the state of the art the work progress represents an implementation of well established torques controlled whole-body control strategies. The integration of tactile feedback within the whole-body controller is a peculiarity of the implemented CoDyCo validation scenario and therefore represent a step forward with respect to the current state of the art. At the moment of writing the current deliverable the iCub tactile sensors cover the feet, the torso, the arms and the hands and the implemented validation scenario accounts for contacts at the hands and feet.

WP6: management (IIT) The CoDyCo project management was concluded successfully. Management activities included the definition of an amendment procedure smoothly organized by the consortium and the project officer. The software repository (`https://github.com/robotology/codyco`) was consolidated on github (`https://github.com`).

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

3.3.2.1 Work package 1 progress

Software architecture design and evaluation of available open-source software pertinent to the scope of the project. (T1.1) The goal of T1.1 was to agree on a specific software architecture with associated software tools whose specifications, dependencies and interconnections meet the requirements and needs for achieving the goals of the project. The software, which is called `codyco-superbuild`, has been available via github on `https://github.com/robotology/codyco-superbuild` since the second year of the project. Details about the modules of the software are available in deliverables D1.1, D1.2 and D1.3.

Simulator for whole-body motion with contacts (T1.2) The CoDyCo project requires a modular, component-based dynamics simulation software providing numerically stable, computationally efficient and physically consistent simulations of whole-body virtual human(oid) systems in contact with rigid or soft environments. During year four the iCub simulator was further developed, keeping it aligned with the robot development.

3.3.2.1.1 Control library for flexible specification of task space dynamics of floating base manipulators. (T1.3) UPMC has kept developing OCRA over the 4th year of CoDyCo. OCRA stands for Optimization-based Control for Robotics Applications. OCRA is a set of tools which facilitates the development of optimization-based controllers for robots. At its core there is ocra-recipes, a group of platform independent libraries which can be used to quickly develop optimization based controllers for any robot. Hierarchical, weighted, and hybrid controller schemes can easily be implemented using the ocra-recipes libraries. The generic interfaces provided by OCRA allow different robots to use the exact same controllers. Examples of such implementations can be found for the humanoid robot iCub (ocra-wbi-plugins), and the 7 DoF Kuka LWR (ocra-kdl). OCRA also allows users to specify high-level objectives via tasks. These tasks provide an intuitive way of generating complex behaviours and can be specified in XML format. In addition, a variety of gazebo plugins and controller visualization tools have been developed to facilitate debugging and tuning of the controller.

Among these plugins, a predictive approach [?] to preview the duration and placement of coplanar contacts has been implemented in the form of a client for OCRA using the iCub humanoid robot. Within a model-predictive control framework, the problem is formulated as a linearly constrained mixed-integer quadratic program (MIQP) which allows the determination over a preview horizon, of the optimal changes in the base of support of the robot with compatible CoM behaviour, subject to multiple constraints, while maximising balance and performance of a walking activity.

3.3.2.1.2 System dynamics estimation software. Extension to environmental compliance estimation (T1.4) The goal of T1.4 was to include compliant contact estimation to the software. This is part of `codyco-superbuild` software which its details are reported in deliverables D1.1, D1.2 and D1.3.

3.3.2.1.3 Extension and enhancement of the iDyn library. (T1.5) As part of this task, INRIA developed several software modules which are all available on github. These modules which have been used as a support for the research in the other WPs are:

- software and GUI for visualizing the whole-body torques of iCub: `https://github.com/inria-larsen/icub-wholebody-visualization`
- software for interfacing the Geomagic software with Gazebo and use it for haptic interaction with iCub: `https://github.com/inria-larsen/geomagic_touch`
- software for learning prioritized controllers, in Matlab, with implementation of constrained stochastic optimization algorithms: `https://github.com/serena-ivaldi/learnOptimWBC`
- software for learning Probabilistic Movements Primitives from trajectories acquired by demonstrations on iCub: `https://github.com/inria-larsen/icubLearningTrajectories`

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	-	-
Year 3	-	1.00	-	2.18	2.00	2.96
Year 4	?	1.00	1.31	?	0.00	2.06
Partial	?	?	?	?	?	?
Overall	12.00	9.00	6.00	15.00	6.00	5.00

Deviations from workplan Overall the project is aligned with the plan.

3.3.2.2 Work package 2 progress

3.3.2.2.1 Definition and design of experimental protocols (T2.1) The explicit goal of T2.1 for the fourth year was to ...

We achieved the following results ...

3.3.2.2.2 Design of models for human whole body motion in contact (T2.2) The explicit goal of T2.2 for the fourth year was to ...

We achieved the following results ...

3.3.2.2.3 Strategies of dealing with uncertainties in contact (T2.3) The explicit goal of T2.3 for the fourth year was to ...

We achieved the following results ...

3.3.2.2.4 Human contact choice and learning through physical interaction (T2.4) The explicit goal of T2.4 for the fourth year was to ...

We achieved the following results ...

Resources Overall, the use of resources within WP2 was in accordance to the plans.

WP2 person months	IIT	TUD	UPMC	UB	JSI	INRIA
Year 1	-	-	0.28	2.64	18.80	-
Year 2	-	3.00	0.48	7.67	21.85	-
Year 3	-	1.00	1.20	13.88	21.69	0.52
Year 4	?	?	?	?	?	?
Partial	?	?	?	?	?	?
Overall	-	4.00	1.00	45.00	55.00	1.00

Deviations from workplan No significant deviations.

3.3.2.3 Work package 3 progress The progress for each task are described hereafter.

3.3.2.3.1 Reproducing existing control results in a simple case (T3.1) The explicit goal of T3.1 for the fourth year was to ...

We achieved the following results ...

3.3.2.3.2 Formulating the control problem (T3.2) The explicit goal of T3.2 for the fourth year was to ...

We achieved the following results ...

3.3.2.3.3 Solving the local control problem (T3.3) The explicit goal of T3.3 for the fourth year was to ...

We achieved the following results ...

3.3.2.3.4 Bootstrapping and validating the control approach in rigid world and compliant cases (T3.4) The explicit goal of T3.4 for the fourth year was to ...

We achieved the following results ...

3.3.2.3.5 Deviations from workplan The PM expenses for WP3 after one year of project are globally conform to the planned one. The observed deviations are related to the fact that tasks 3.3 and 3.4 spans the overall duration of the project and the contribution of some of the partners are expected in the 2nd, 3rd and 4th year.

3.3.2.3.6 Resources

WP3 person months	IIT	TUD	UPMC	UB	JSI	INRIA
Year 1	9.90	4.60	15.15	-	-	-
Year 2	-	10.5	14.67	1.85	1.00	4.14
Year 3	-	9.65	8.79	1.63	2.00	4.03
Partial	9.90	24.75	38.61	3.48	3.00	8.17
Year 4	?	?	?	?	?	?
Partial	?	?	?	?	?	?
Overall	9.00	24.00	43.5	10.00	4.00	10.50

In order to best use the whole-body controllers developed within the framework of WP3, TUD hired a student for setting up the iCub hardware and simulation environment.

Deviations from workplan No deviations.

3.3.2.4 Work package 4 progress The progress for each task are described hereafter.

3.3.2.4.1 Learning the Prioritization of Tasks (T4.4) (TUD: 4PM) TUD continued its research on learning task prioritizations from human demonstrations using probabilistic models. This work is currently under review and a draft of the paper was added to Deliverable D4.3 in Section 5. Here is a short summary of the approach.

Movement prioritization is a common approach to combine controllers of different tasks for redundant robots. Each task is assigned a priority, where either strict or 'soft' priorities can be used. While movement prioritization is an important concept in the control of whole body movements, it has been less considered in learning-based approaches, where prioritization allows us to learn different tasks for different end-effectors, and subsequently reproduce an arbitrary, unseen combination of these tasks. This paper combines Bayesian task prioritization, a 'soft' prioritization technique, with probabilistic movement primitives to prioritize full motion sequences. Probabilistic movement primitives can encode distributions of movements over full motion sequences and provide control laws to exactly follow these distributions. The probabilistic formulation allows for a natural application of Bayesian task prioritization. We demonstrate how the 'soft' priorities can be obtained from imitation learning and that our prioritized learning architecture can reproduce unseen task-combinations. Moreover, we require less data to learn a combination of tasks than the traditional approach that directly models each task in joint space. We evaluate our approach on reaching movements under constraints with a redundant bi-manual planar robot and the humanoid robot iCub.

3.3.2.4.2 Learning the Prioritization of Tasks (T4.4) (INRIA: 4.02PM) INRIA continued its research on automatically learning soft task priorities (or task weights) using stochastic optimization algorithms. The research is presented in Deliverable D4.3.

The motivation for the work was to provide an automatic way of determining the temporal profile of the soft task priorities, that are classically manually tuned by experts. When done manually, the critical issue is to define the task transitions, i.e., to define when a task becomes "less important" and its weight diminishes, and viceversa.

In a first paper [**?**], in collaboration with TUD, we investigated how to learn the temporal profile of the soft task priorities (or task weights) in a reinforcement learning scenario. We represented the soft task priorities with parametrized weight functions, and used CMA-ES (Covariance Matrux Adaptation Evolution Strategy, a state-of-the-art blakc-box stochastic optimization algorithm) to optimize their parameters. We showed on a simulated and real robot manipulators that our method was able to obtain better performing solutions that the classic hand-tuned Generalized Hierarchical Controller (developed in WP3).

In a second paper [**?**] we focused on learning soft task priorities while guaranteeing that the generated behaviors are "safe", i.e., that they never violate any of the constraints of the robot and of the system. Indeed, CMA-ES was chosen because of its good exploration properties and ease of use (very few parameters to tune), however it does not take into account constraints violations during the exploration. In [**?**], the solutions that were not feasible were simply discarded. In [**?**] we investigated constrained stochastic optimization algorithms, focusing on three variants of CMA-ES: CMA-ES with vanilla constraints, CMA-ES with adaptive constraints and (1+1)-CMA-ES with covariance constrained adaptation. We compared the three algorithms on different benchmarks: classical constrained optimization problems with known solutions and two constrained robotics problems of our design. We found that the third method satisfies our requirements, specifically it always leads to solutions that never violate constraints. We showed the effectiveness of the approach by generating safe whole-body behaviors of iCubNancy01.

Resources

WP4 person months	IIT	TUD	UPMC	UB	JSI	INRIA
Year 1	-	8.00	2.22	-	-	-
Year 2	6.04	21.70	1.69	2.15	3.00	2.01
Year 3	9.79	12.00	0.74	1.68	3.00	3.30
Year 4	?	4	?	?	?	4.02
Partial	?	45.7	?	?	?	?
Overall	30.00	38.00	9.00	12.00	10.00	9.00

Deviations from workplan No deviations.

3.3.2.5 Work package 5 progress The activities in WP5 are divided into four tasks corresponding to the four years project duration. As a result, during the fourth year CoDyCo results concentrate on T5.4. The main result consist in the implementation of the validation scenario consisting of the balancing with the help of a caregiver. The main scientific contribution is described here [**?**].

3.3.2.5.1 Scenario 4: learning how to stand up with the help of a human caregiver (T5.4) The main contributions to T5.4 have been presented in "Validation scenario 4: learning how to stand up with the help of a human caregiver" which discusses the technical implementation of the fourth year validation scenario (see `https://github.com/robotology-playground/codyco-deliverables/tree/master/D5.4/pdf`). The software developed for the scenario implementation is released with an open-source license and distributed through github (`https://github.com/robotology/codyco`).

3.3.2.5.2 Deviations from workplan No deviations.

Resources Resources were used with no difference with respect to what planned.

WP5 person months	IIT	TUD	UPMC	UB	JSI	INRIA
Year 1	2.00	-	0.31	-	-	-
Year 2	12.00	0.85	0.05	-	-	-
Year 3	13.06	2.00	0.14	1.44	-	0.52
Year 4	?	?	?	?	?	?
Partial	?	?	?	?	?	?
Overall	48.00	5.00	2.50	-	-	1.50

Deviations from workplan No significant deviations from the workplan. The validation scenarios will include all the theoretical and technological challenges detailed in the original plan.

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 result, the software repository was consolidated thanks to the versioning tool (git) and social coding website (`https://github.com`).

3.3.2.6.1 Administrative coordination (T6.1) Administration was successfully coordinated by Chiara Andreoli at IIT. The major activity concerned an amendment that the CoDyCo consortium asked the main reason being the fact that Serena Ivaldi, initially hired by UPMC, lately moved to UPMC and finally integrated in the consortium with INRIA. Part of the administrative coordination activities were also conducted during the mid-year meeting: Nancy, November 22nd, 2016. 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) A github software repository was set up `https://github.com/robotology/codyco` and the contribution from the different developers can be directly checked in the website.

Resources Resources were used as follows.

WP6 person months	**IIT**	**TUD**	**UPMC**	**UB**	**JSI**	**INRIA**
Year 1	1.46	-	0.25	-	-	-
Year 2	1.50	-	0.31	-	-	-
Year 3	1.51	1.00	0.19	-	0.44	-
Year 4	?	?	?	?	?	?
Partial	?	?	?	?	?	?
Overall	5.00	1.00	1.00	0.60	1.00	-

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) The explicit goal of T7.1 for the fourth year was to ...

We achieved the following results ...

3.3.2.7.2 Exploitation plan (T7.2) The explicit goal of T7.2 for the fourth year was to ...

We achieved the following results ...

3.3.2.7.3 Management of IPR (T7.3) The explicit goal of T7.3 for the fourth year was to ...

We achieved the following results ...

3.3.2.7.4 Dissemination of a database of human motion with contacts (T7.4)

The explicit goal of T7.4 for the fourth year was to ...

We achieved the following results ...

Resources Resources were used as follows.

WP7 person months	**IIT**	**TUD**	**UPMC**	**UB**	**JSI**	**INRIA**
Year 1	1.00	-	0.40	-	-	-
Year 2	-	-	0.13	-	-	0.91
Year 3	1.00	-	0.11	-	-	-
Year 4	?	?	?	?	?	?
Partial	?	?	?	?	?	?
Overall	3.00	1.00	1.00	1.00	1.00	1.00

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