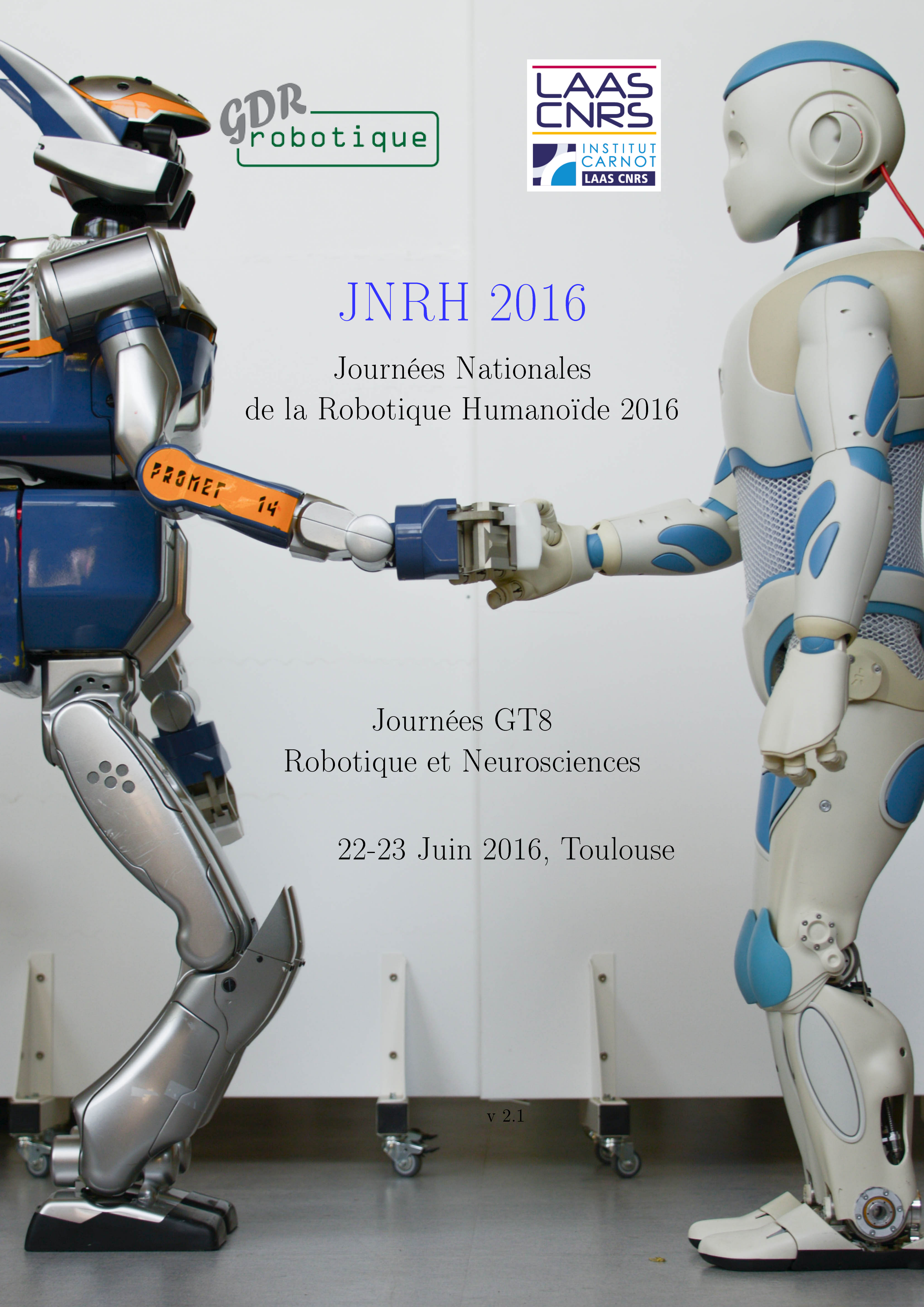


GDR robotique

LAAS CNRS
INSTITUT CARNOT
LAAS CNRS

# JNRH 2016

## Journées Nationales
## de la Robotique Humanoïde 2016

Journées GT8
Robotique et Neurosciences

22-23 Juin 2016, Toulouse

v 2.1

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# Journées Nationales de la Recherche Humanoïde 2016 co-organisées avec les Journées GT8 Robotique et Neurosciences

Laboratoire d'Analyse et d'Architecture des Systèmes

22-23 Juin, 2016

## Mercredi, 22 Juin 2016

| | |
|---|---|
| 8:45-9:15 | Accueil |
| 9:15-9:20 | **Introduction: O. Stasse** |
| 9:20-10:20 | Session Plénière<br>**HYDROÏD: Humanoid platform with Integrated Hydraulic Actuation**<br>*Samer Alfayad, LISV* |
| 10:20-10:40 | Pause café |
| 10:40-12:10 | Session Interaction homme/robot |
| 10:40-11:10 | **HPP: a software framework for motion and manipulation planning**<br>*J. Mirabel et F. Lamiraux, LAAS* |
| 10:10-11:40 | **Demonstrating to a humanoid robot how to conduct neuropsychological tests**<br>*D. C. Nguyen, G. Bailly et F. Elisei, GIPSA-LAB* |
| 11:40-12:10 | **Plasticité et boucle sensori-motrice pour l'émergence de synchronie dans l'interaction rythmique homme/robot**<br>*P. Hénaff, LORIA* |

| | |
|---|---|
| 12:20-13:30 | Déjeuner |
| 13:30-15:30 | Session Mécatronique |
| 13:30-14:00 | **Child Exoskeleton Mechatronic Design**<br>*M. Kardofaki, M. Fouz, S. Alfayad et F. Ben Ouezdou, LISV* |
| 14:00-14:30 | **Retrofit de BIP : stabilité posturale des robots marcheurs**<br>*J. Gastebois, A. Eon, P. Laguillaumie, P. Seguin et S. Zeghloul, PPrime* |
| 14:30-15:00 | **Weight Optimization of HYDROÏD Humanoid Robot - New methodologies and Advanced material**<br>*M. Elasswad, S. Alfayad, K. Khalil et F. Ben Ouezdou, LISV* |
| 15:00-15:30 | **Romeo and the Stack of Tasks**<br>*K. Giraud-Esclasse, F. Forget, O. Stasse et N. Mansard, LAAS* |
| 15:30-16:00 | Pause café |
| 16:00-18:00 | Session Génération de mouvements |
| 16:00-16:30 | **GPU-based Semi-Infinite Optimization for Whole-Body Robot Control**<br>*B. Chrétien, A. Escande et A. Kheddar, LIRMM, JRL* |
| 16:30-17:00 | **Combining visual servoing and walking in an acceleration resolved whole-body control framework**<br>*D.-J. Agravante, F. Chaumette, LAGADIC* |
| 17:00-17:30 | **Dual arm manipulation and whole body control with the humanoid robot Romeo by visual servoing**<br>*G. Claudio, D. J. Agravante, F. Spindler and F. Chaumette, LAGADIC* |
| 17:30-18:00 | **Motion Generation for Pulling a Fire Hose by a Humanoid Robot**<br>*I. G. Ramirez-Alpizar, M. Naveau, C. Benazeth, O. Stasse, J.-P. Laumond, K. Harada, and E. Yoshida LAAS, AIST* |
| 18:00 | Fin des sessions pour la journée |
| 19:15 | **Diner** (embarquement Port Saint Sauveur - Métro François Verdier - voir plan) |

# Jeudi, 23 Juin 2016

| | |
|---|---|
| 9:20-10:20 | Session Locomotion avec multi-contacts |
| 9:20-9:50 | **A versatile and efficient framework for multi-contact legged locomotion**<br>*J. Carpentier et S. Tonneau, LAAS* |
| 9:50-10:20 | **Zones de support du ZMP pour la locomotion multi-contact**<br>*S. Caron, LIRMM* |
| 10:20-10:40 | Pause café |
| 10:40-12:10 | Session Contrôle |
| 10:40-11:10 | **Commande de gestion d'équilibre pour un exosquelette de jambes**<br>*V. Huynh, C. Bidard, C. Chevallereau, CEA, IRCCyN* |
| 11:10-11:40 | **Stratégie de chute et réglage de gains en temps-réel**<br>*V. Samy, A. Kheddar, LIRMM* |
| 11:40-12:10 | **Attitude Estimation and Stabilization of a Compliant Humanoid Robot Using Only Inertial Measurement Units**<br>*A. Mifsud, M. Benallegue, F. Lamiraux, LAAS* |
| 12:10-13:10 | Déjeuner |
| 13:10-13:30 | **Démonstrations HRP-2 et Romeo**<br>*M. Naveau, T. Flayols, F. Forget, O. Stasse, LAAS* |
| 13:30-16:45 | Session Modèles de la marche chez l'homme et les robots |
| 13:30-14:00 | **Comment la forme des trajectoires locomotrices révèle le rôle de la vision ?**<br>*J.-P. Laumond, LAAS* |
| 14:00-14:30 | **Exploring Walking Patterns of Cerebral Palsy Children by Numerical Simulation**<br>*A. P. Dos Santos, F. Ben Amar, P. Bidaud, V. Padois et E. Desailly, ISIR* |
| 14:30-15:00 | **How do walkers avoid a mobile robot crossing their way?**<br>*C. Vassallo, AH. Olivier, P. Souères, A. Crétual, O. Stasse, J. Pettré, LAAS, IRISA* |
| 15:00-15:30 | Pause café |
| 15:30-16:00 | **Energetic Comparison of Spring Mass Model and Poly-Articulated Model during human gait**<br>*B. Watier, P. Moretto, LAAS, CRCA* |
| 16:00-16:30 | **Evaluation of an inverse KKT approach on a human walking task**<br>*A. Panchea, S. Miossec, O. Buttelli, P. Fraisse, N. Ramdani, PRISME, LIRMM* |
| 16:30-17:00 | **Robust human-inspired power law trajectories for humanoid HRP-2 robot**<br>*M. Karklinsky, M. Naveau, A. Mukovskiy, O. Stasse, T. Flash, P. Soueres, Weizmann Institute, LAAS* |
| 17:00-17:05 | Conclusions - Fin des journées |

# Dîner

Le dîner prendra place dans le bateau LE CAPITOLE, de la société LES BATEAUX TOULOUSAINS.

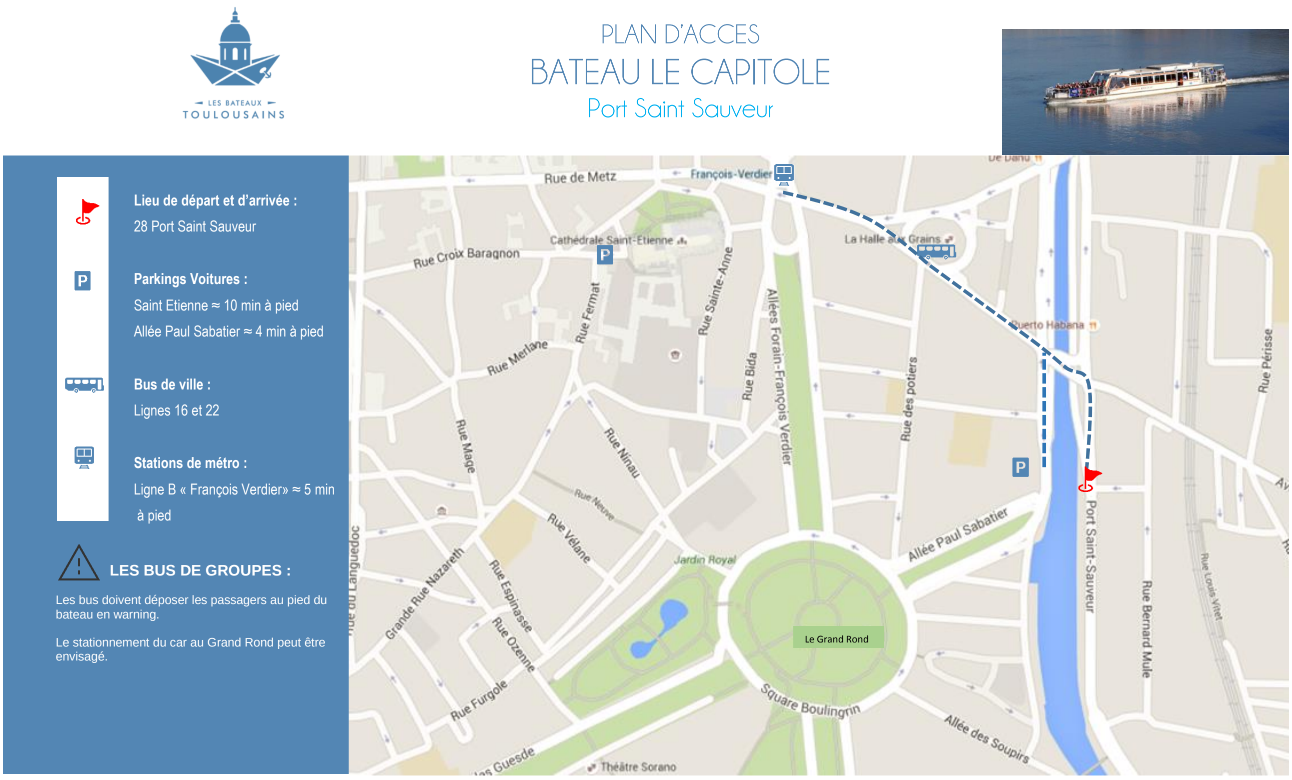
Le départ est prévu à 19h30 au 28 Port Saint Sauveur, du côté opposé à la caserne des pompiers.

Rendez-vous donc à 19h15.

Le métro le plus proche est François Verdier (Ligne B).

Le repas prendra fin à 22h30.

La promenade prendra place le long du canal du Midi.



## Lieu

Les journées prendront place :
Salle de Conférences,
LAAS, CNRS,
7, avenue du Colonel Roche
BP 54200
31031 Toulouse cedex 4

Localisation https://goo.gl/maps/XjuBPmz23N42
Plus d'informations sont disponibles ici.

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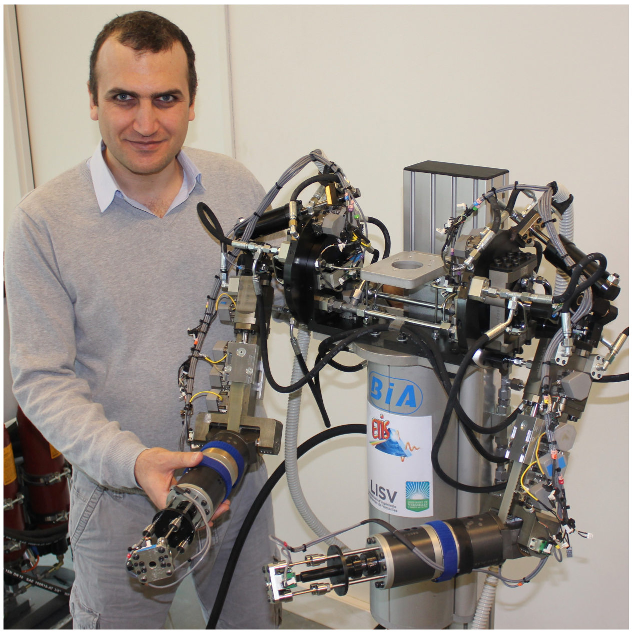
# HYDROïD: Humanoid platform with Integrated Hydraulic Actuation

HYDROïD (HYDraulic andROïD) is a full-size under development humanoid robot aims to contribute to improving our understanding of the phenomena of locomotion and manipulation of humans. Humanoid with hydraulic actuation are able to achieve hard and useful tasks and replace human in disaster environment.

In hydraulic actuation, pistons are used to produce motion. At least one hydraulic piston is implemented for each degree of freedom (DoF). The main difficulty is how to bring hydraulic energy to each piston. Hydraulic pipes are usually employed to drive hydraulic power from the control unit to pistons. Each piston needs two pipes, one to drive fluid "in" and the other to drive it "out". In robotic applications, flexible hydraulic pipes are used to drive the oil in parallel to the joints. This solution suffers from three main disadvantages: I) The hydraulic pipes connected in parallel to joint will give a spring effect. This phenomenon has to be considered while developing the control law. II) The more the number of pipes, the more of the leakage probabilities. III) External pipes increase dramatically the robot size and decrease its anthropomorphic aspects.

To answer all these questions, a new "integrated hydraulic actuation" method was proposed and implemented on HYDROïD. The goal is to eliminate all external pipes and replace them with integrated hydraulic passages. Fluid paths is integrated internally through the mechanical structure and not externally through pipes. In other words, "arteries" and "veins" were built inside the HYDROïD body to drive hydraulic fluid like blood in human body.




This presentation will focus on two research areas. First, we will focus in two innovative hybrid mechanisms, each consisting of a rotating actuator carrying a parallel structure with two active DoF. The first type has been dedicated to the modules of the hip, shoulder and torso. The second type, actuation of parallel structure with cables was chosen for the ankle, the wrist and the neck modules.
The second part of this presentation will be dedicated to the actuation of the HYDROïD robot for which a new highly integrated actuator has been proposed. The actuation principle will be detailed and the benefits of the proposed solution will be shown. Very interesting performance of the realized prototype will be presented.

Biography

Samer Alfayad received his master diploma in sciences and technology from Ecole Nationale Supérieure d'Arts et Métiers (ENSAM-Paris) in 2005. His Ph.d was received in Robotic development from Versailles University (UVSQ) in 2009. Awarded of the best Ph.D Thesis in Robotics for 2010 by the French CNRS. Awarded of the best Ph.D Thesis in Robotics for the 20 years anniversary of UVSQ. From 2009 to 2010, he was a Psot-doc at UVSQ. From 2010 to 2011 he was a Post-doc at Technische Universitat Munich (TUM-Germany) with a Scholarship from the Alexander Von Humboldt foundation. In 2011 he has been appointed as Associated Professor in Humanoid robotic design at Versailles University. From 2012, he holds an industrial excellence chair about hydraulic domestication at UVSQ. He has been investigator in several French National projects. He is the leader of the Humanoid research group at LISV. He is leading currently the team in charge of HYDROïD (anthropomorphic biped robot) development.

# HPP: a software framework for motion and manipulation planning

J. Mirabel[1] and F. Lamiraux[1] *

## Résumé

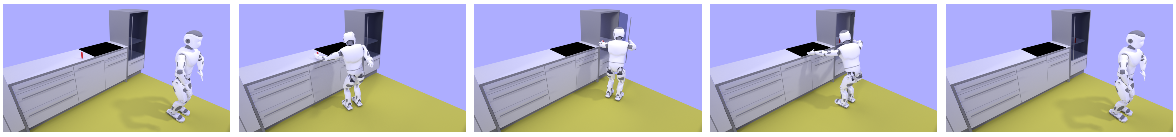


FIGURE 1: Romeo puts a box in a fridge.

We consider a class of advanced motion planning problems including object manipulation, navigation among movable obtacles and legged locomotion. Our approach uses rearrangement rules, encoded in a Constraint Graph, a formula- tion unifying high-level task planning and motion planning. Our method can compute manipulation paths for complex robots and movable - articulated - objects in a static environment, allowing for instance to generate continuous grasps and object placements. A new planning algorithm, Manipulation RRT, makes use of the Constraint Graph to solve Rearrangement problems and to produce rich feedbacks to higher level plan- ners. Simulation results, for problems where movable objects must be manipulated simultaneously or several times, involving humanoid robots, are presented.

The presented work is fully integrated in the Humanoid Path Planner [1] framework.

## Références

[1] J. Mirabel, S. Tonneau, P. Fernbach, A.-K. Seppälä, M. Campana, N. Mansard and F. Lamiraux, “HPP: a new software for constrained motion planning“, 2016

*[1] are with CNRS, LAAS, 7 avenue du colonel Roche, F-31400 Toulouse, France, {jmirabel,florent}@laas.fr

# Demonstrating to a humanoid robot how to conduct neuropsychological tests

Duc Canh Nguyen, Gérard Bailly & Frédéric Elisei

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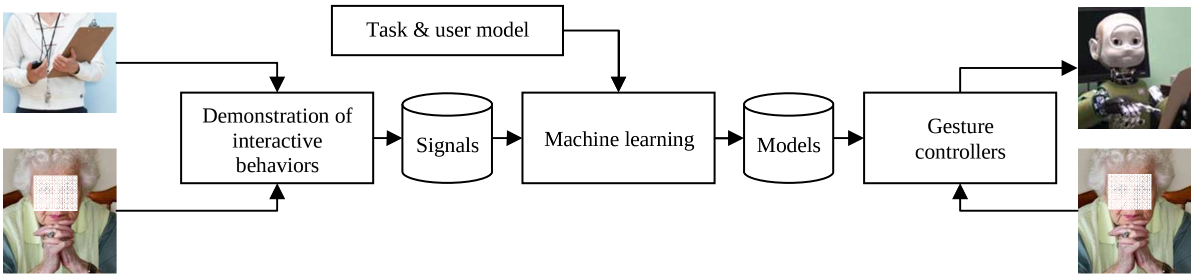


**Figure 1. The three main steps of learning interaction by demonstration**

## ABSTRACT
Several socially assistive robot (SAR) systems have been proposed and designed to engage people into various interactive exercises such as physical training [1], neuropsychological rehabilitation [2] or cognitive assistance [3]. While the interactive behavioral policies of most systems are scripted, we discuss here key features of a new methodology we developed in the framework of the SOMBRERO project[1] that enables professional caregivers to teach a SAR how to perform the assistive tasks while giving proper instructions, demonstrations and feedbacks.

## 1 THE SOMBRERO FRAMEWORK
The three main steps of learning interaction by demonstration are given in Figure 1: we should (1) collect representative interactive behaviors from human coaches, notably when the interaction is conducted by professional coaches; (2) build comprehensive models of these overt behaviors and a priori knowledge (task & user model, etc); and then (3) provide the target robot with appropriate gesture controllers to execute the desired behaviors.

This framework faces several problems: (1) the scaling of the human model to the interaction capabilities of the robots in terms of physical limitations (degrees of freedom) and perception, action and reasoning; (2) the drastic changes of human behaviors in front of robots or virtual agents [4]; (3) the modeling of joint interactive behaviors (4) the replay and assessment of these behaviors by the robot.

SOMBRERO proposes to solve the two first issues by enabling coaches to demonstrate human-robot interaction (HRI) via immersive teleoperation, i.e. by direct robotic embodiment. The so-called *beaming* of the gaze and lip movements of our iCub robot Nina is described in [5]. The signals in Figure 1 are thus already HRI data because the human pilot has artificially provided the SAR with cognitive skills that are adapted to the robot sensorimotor abilities.

The third issue has been addressed by Mihoub et al [6], [7]. They proposed to train statistical behavioral models that jointly map discrete multimodal events performed by the interlocutors.

## 2 THE CURRENT CONTRIBUTION
We address here the fourth issue i.e. the replay and assessment of interactive behaviors by the robot. We should in fact verify that the planned multimodal behaviors can be effectively reproduced by the target robot and that they are perceived as adequate by human interlocutors.

### 2.1 The scenario
These interviews are based on the French adaptation [8] of the Selective Reminding Test [9] named the RL/RI 16. It provides a simple and clinically useful verbal memory test for identifying loss of episodic memory in the elderly. The RL/RI 16 protocol consists in four phases: (1) the progressive learning of 16 words together with their semantic categories; (2) three successive recall tasks (free recall, complemented by an indexed-by-category recall for the unrecovered items) separated with a distractive task (reverse counting); (3) a recognition task involving the 16 items, 32 distractors (16 different words with the same semantic category and 16 true distractors) and (4) a delayed free and indexed recall (not administrated in the present study). Mnesic performance is evaluated by comparing recall rates of the subject with regards to mean & standard deviations observed within sane control population of the same age interval.

### 2.2 Interactive data
The behavioral data of the interviewer served as demonstration for the humanoid robot. Since beaming of the upper body (notably of the arms) was not available, the discrete multimodal events have been collected via semi-automatic labelling of human-human interactions (HHI). The motion of 25 retroflexive markers placed on the plexus, shoulders, head, arms, indexes and thumbs of the professional interviewer were monitored thanks to a Qualysis® system with 4 cameras. A Pertech® head-mounted monocular eyetracker also monitors the gaze of the interviewer (see Figure 2). Speech data are captured via OKMII high-quality ear microphones and are recorded synchronously with a side-view video by HD camera.

**Figure 2. Visual data. Right: side view from a fixed HD camera. Left: head-related view from the eyetracker scene**

[1] See http://www.gipsa-lab.fr/projet/SOMBRERO

**camera. The dot superimposed to the scene camera features the current gaze fixation point.**

Each interview lasts around 20", comprising the collection of personal records, the core RL/RI protocol and final report of performance. We analyze here a total two hours of multimodal data for five subjects, interacting with a unique interviewer (a medical one, professionaly trained to conduct these RL/RI tests).

### 2.3 Gestural scores

Elan[10] (see Figure 3) and Praat [11] were used to semi-automatically identify speech, gaze and arm events. Behavioral models have to orchestrate these events according to the task and should be able to generate motor actions from percepts. Modality-specific gesture controllers have then to reproduce final motions from these discrete motor events.

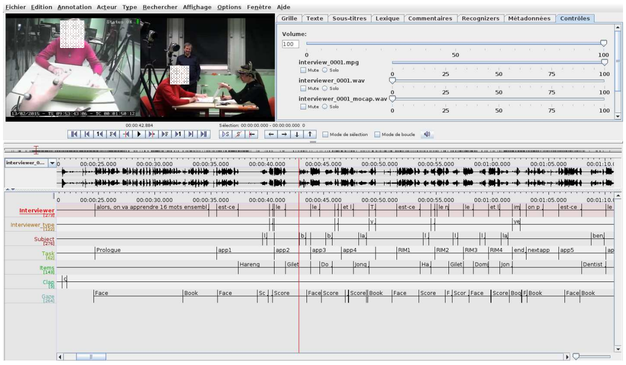

**Figure 3. Labelling gaze & speech events with Elan.**

### 2.4 Gesture controllers

***Speech.*** We transcribed speech and aligned its phonetic content with the acoustic signals uttered by both the interviewer and the subjects. The subject's speech is mainly used to trigger scoring. The interviewer's speech was analyzed more in depth with a special attention to prosody and in particular to backchannels [12]. The transcription together with prosodic markers is then played by the audiovisual text-to-speech synthesizer controlling Nina's loudspeaker and facial movements [13]

***Arm gestures.*** While the human interviewer was displaying word items and scoring using sheets of paper, we decided to use tablets to display items and pretend to trigger the display and take notes (see xx). Arm displacements and finger clicks are then programmed to trigger display on the subject's tablet (show/hide items) and take notes (monitor correct responses).

***Gaze.*** We distinguish three main region of interest of the interviewer's gaze: (1) the subject's face; (2) the scoring tablet (i.e. scoring sheet and chronometer for original HHI); (3) the subject's tablet (i.e. notebook for HHI). All arm gestures are performed with visuomotor supervision: since robot motion is often slower than human motion, all arm motions are preceded by one fixation towards the target if any and accompanied by gaze smooth pursuit till completion. This visuomotor supervision supersedes any other observed fixation pattern.

## 3 EVALUATION

These complex and coordinated behaviors should be perceived and interpreted correctly by subjects. We have shown that the morphology and appearance of effectors can strongly impair the perception of planned gestures [14]. We are thus planning to ask third parties to rate the final rendering of this multimodal score. In line with online evaluation methods deployed for audio [15] and video [16], we are planning to ask subjects to put themselves in the place of our subjects and rate the adequacy of the SAR's behavior with regards to the subjects' verbal behavior.

## 4 CONCLUSIONS

We proposed here an original framework for collecting, modelling and controlling SAR. All the building blocks are almost operational and have been evaluated separately. We plan to conduct robot-mediated HHI very soon and see what parts of this framework should be corrected. One of the key challenges is system's adaptation. Mihoub et al [7] have shown that a subject-independent gaze model may be parametrized to adapt to specific social profiles. We will see if this approach scales to multimodal behavior planning and control.

## REFERENCES


[1] J. Fasola and M. Mataric, "A socially assistive robot exercise coach for the elderly," *Journal of Human-Robot Interaction*, vol. 2, no. 2, pp. 3–32, 2013.

[2] J.-J. Cabibihan, H. Javed, M. Ang, and S. M. Aljunied, "Why Robots? A survey on the roles and benefits of social robots in the therapy of children with autism," *International Journal of Social Robotics*, vol. 5, no. 4, pp. 593–618, 2013.

[3] M. E. Pollack, L. Brown, D. Colbry, C. E. McCarthy, C. Orosz, B. Peintner, S. Ramakrishnan, and I. Tsamardinos, "Autominder: An intelligent cognitive orthotic system for people with memory impairment," *Robotics and Autonomous Systems*, vol. 44, no. 3, pp. 273–282, 2003.

[4] M. L. Walters, D. S. Syrdal, K. Dautenhahn, R. te Boekhorst, and K. L. Koay, "Avoiding the uncanny valley: robot appearance, personality and consistency of behavior in an attention-seeking home scenario for a robot companion," *Autonomous Robots*, vol. 24, no. 2, pp. 159–178, 2008.

[5] G. Guillermo, P. Carole, F. Elisei, F. Noel, and G. Bailly, "Qualitative assesment of a beaming environment for collaborative professional activities," in *European conference for Virtual Reality and Augmented Reality (EuroVR)*, 2015, p. 8 pages.

[6] A. Mihoub, G. Bailly, C. Wolf, and F. Elisei, "Graphical models for social behavior modeling in face-to face interaction," *Pattern Recognition Letters*, vol. 74, pp. 82–89, 2016.

[7] A. Mihoub, G. Bailly, and C. Wolf, "Learning multimodal behavioral models for face-to-face social interaction," *Journal on Multimodal User Interfaces (JMUI)*, vol. 9, no. 3, pp. 195–210, 2015.

[8] M. Van der Linden, F. Coyette, J. Poitrenaud, M. Kalafat, F. Calicis, C. Wyns, and S. Adam, "L'épreuve de rappel libre / rappel indicé à 16 items (RL/RI-16)," in *L'évaluation des troubles de la mémoire : présentation de quatre tests de mémoire épisodique avec leur étalonnage*, M. Van der Linden, Ed. Marseille, France: Solal, 2004, pp. 25–47.

[9] E. Grober and H. Buschke, "Genuine memory deficits in dementia," *Developmental Neuropsychology*, vol. 3, pp. 13–36, 1987.

[10] B. Hellwig and D. Uytvanck, "EUDICO Linguistic Annotator (ELAN) Version 2.0.2 manual," Max Planck Institute for Psycholinguistics, Report, 2004.

[11] P. Boersma and D. Weenink, *Praat, a System for doing Phonetics by Computer, version 3.4*. 1996.

[12] Bailly, Gérard, Elisei, Frédéric, Juphard, Alexandra, and Moreau, Olivier, "Quantitative analysis of backchannels uttered by an interviewer during neuropsychological tests," in *Interspeech*, San Francisco, CA, submitted.

[13] A. Parmiggiani, M. Maggiali, L. Natale, F. Nori, A. Schmitz, N. Tsagarakis, J. S. Victor, F. Becchi, G. Sandini, and G. Metta, "The design of the iCub humanoid robot,"

*International Journal of Humanoid Robotics*, vol. 9, no. 4, p. 24 pages, 2012.
[14] F. Foerster, G. Bailly, and F. Elisei, “Impact of iris size and eyelids coupling on the estimation of the gaze direction of a robotic talking head by human viewers,” in *Humanoids*, Seoul, Korea, 2015.
[15] M. Hansen and B. Kollmeier, “Continuous assessment of time-varying speech quality,” *Journal of the Acoustical Society of America*, vol. 105, no. 5, pp. 2888–2899, 1999.
[16] Hamberg, Roelof and de Ridder, Huib, “Continuous assessment of perceptual image quality,” *Journal of the Optical Society of America*, vol. 12, no. 12, pp. 2573–2577, 1995.

# Plasticité et boucle sensori-motrice pour l'émergence de synchronie dans l'interaction rythmique homme/robot

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**Résumé de la présentation :**

L'exposé sera consacré à l'émergence de phénomènes de synchronie dans l'interaction physique et rythmique Homme-Homme et Homme-robot, en se focalisant sur l'acte commun de la poignée de main. Une première partie introduira le rôle de la synchronie et des phénomènes de verrouillage dans l'interaction sociale interpersonnelle. Dans une seconde partie, nous montrerons les résultats issus d'expériences menées au LORIA sur la poignée de main entre humains en insistant sur les phénomènes physiques mis en jeu (forces de serrage, accélérations, vitesses) et leur dépendance au contexte social dans lequel cet acte est accompli. Les phases d'approche et de synchronisation des modes rythmiques seront particulièrement analysées. Dans une troisième partie, nous verrons comment reproduire ces phénomènes entre un humain et un bras robotique grâce à un contrôleur articulaire issus de nos travaux précédents sur les centres générateurs de rythmes (CPG ou central pattern generators). Nous analyserons le rôle important des retours sensoriels articulaires vers ce CPG (position, vitesse, accélération, couple) dans le phénomène de synchronisation des mouvements des bras humain et robotique. Puis, nous montrerons comment, à partir d'une loi d'adaptation de la fréquence, on peut implémenter une loi de plasticité pseudo-Hebbienne dans le CPG qui permet au contrôleur neuronal du robot d'apprendre à se synchroniser sur le mouvement imposé par l'humain. Une conclusion et des perspectives termineront l'exposé.

# Child Exoskeleton Mechatronic Design

KARDOFAKI Mohamad, FOUZ Moustafa, ALFAYAD Samer

## Abstract

Over 68 million people worldwide are in wheelchair. However, unfortunately, the number of people who need wheelchairs in the world is certainly much more than 68 million, whereas the children aged 0-14 years old are making up a considerable section of this population. In order to improve the social statements of the patients and the wheelchair users, and to make them interact in another way with their environment, the use the wheelchair can be replaced by an orthotics systems which make them having the ability to stand up, sit down and walk again. Exoskeletons are becoming a powerful tool to help in the rehabilitation of patients who have suffered from neurological conditions, in particular stroke or spinal cord injury. This work presents the mechatronic design of robotic exoskeleton dedicated for paralyzed children.

The exoskeleton has six degrees of freedom (Hip, Knee, and ankle for each leg) where four DOF are active for the hip and the knee, and 2 are passive for ankles. Its structure design is modular and adjustable; thanks to using high strength and lightweight composite materials. Hence, it can be adapted to different sizes of persons with the range of 1.20 and 1.90 m tall with a maximum body weight of 100kg. Therefore depending on injury level and control strategy, some additionally security devices may be necessary such as crutches, parallel bars or safety harness.

The selection and design of the actuators were based on calculated values of torque, speed, and power of each active joint (Hip, Knee) along the gait cycle during normal gait at normal speed. The criteria to be taken into consideration are high compactness, lightweight, and specific power to weight ratio. To achieve this criteria, the proposed solution is based on a frameless brushless DC motor that has high efficiency, high torque density, high level of reliability, long lifetime ...etc. The DC motor is coupled to a strain wave gearbox which is characterized by no backlash, compactness, high gear ratios, high torque capability, coaxial input and output shafts, good resolution and excellent repeatability when repositioning inertial loads.

The still under development, control addresses the high level controller (HLC), and low level controller for each joint. The HLC is used to synchronize the motion of the actuators, by assigning trajectories to each of them, and also, it should manipulate the system stability issue while executing the user commands. Preliminary tests and results for operation and communication have been achieved.

# Retrofit de BIP : stabilité posturale des robots marcheurs

*Gastebois J. - Eon A. - Laguillaumie P. - Seguin P. - Zeghloul S. Université de Poitiers-Institut PPrime UPR CNRS 3346*

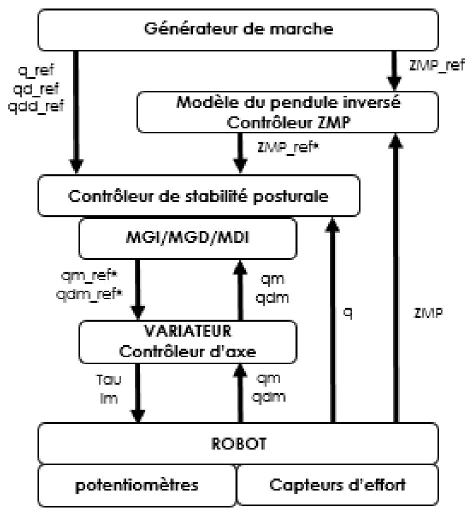
***De la nécessité d'une mise à jour***

Afin d'exploiter la mécanique originale et innovante de BIP 2000 et devant le constat d'une obsolescence matérielle et logicielle, de nombreuses mises à jour ont été effectuées, notamment un nouveau contrôleur écrit sous B&R automation studio. Les nouveaux variateurs utilisés ont permis de réduire la masse de 20 kilos sur les 105 initiaux.

***Objectifs***

Le but de ce projet est de réaliser à terme une commande haut niveau visant l'élaboration de stratégies d'évitement des chutes, en utilisant le ZMP comme critère de non basculement, le tout étant embarqué, en temps réel, sur le système locomoteur BIP. Un jalon intermédiaire vise la validation des développements sur une jambe seule.

**Architecture de commande**




***Travaux réalisés***

Les premières étapes du projet ont été :

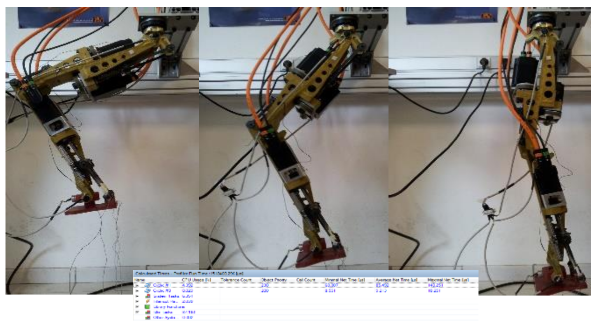
- La réalisation d'un simulateur du robot permettant la génération et la validation de trajectoires et de lois de commande;
- La préparation matérielle de la jambe, son câblage et sa transmission;
- Le montage de la baie de variateurs et de l'acquisition des capteurs d'efforts et de positions;
- Le développement du contrôleur en C orienté objet afin de suivre l'évolution du robot (4DDL vers celui à 15DDL).

***Travaux en cours***

Le but étant de réaliser une marche avec pour référence le ZMP, on a choisi d'instrumenter le pied du robot (capteur d'effort) afin d'en récupérer la mesure. Une procédure de calibrage des capteurs est en cours, parallèlement au développement de la commande référencée ZMP.

***Résultats préliminaires***

Les premiers tests montrent que le calcul en ligne de l'ensemble des modèles du robot et de sa trajectoire est temps réel avec une moyenne de 85 microsecondes pour une boucle à 2 millisecondes avec une erreur de trainée moteur de 0.02 degrés.



***Perspectives***

A court terme, il s'agit de poser le robot au sol et de tester la commande référencée ZMP. Puis dans un second temps une version à deux jambes et enfin le système locomoteur complet.

***Principales références bibliographiques***

Sardain, P., Rostami, M., Bessonnet, G.: An anthropomorphic biped robot: Dynamic concepts and technological design. IEEE Trans. Syst. Man Cybern. Part A: Syst. Hum. 28, 823–838 (1998)

A.Eon, S.*Zeghloul* "Contribution à la génération de mouvements dynamiques pour les robots humanoïdes et au dimensionnement de leurs actionneurs"

S.Kajita, M.Morisawa, K.Miura, S.Nakaoka, K.Harada, K.Kaneko, F.Kanehiro and K.Yokoi, "Biped Walking Stabilization Based on Linear Inverted Pendulum Tracking, Proceedings of 2010 IEEE/RSJ International Conference on Intelligent Robots and Systems, pp.4489-4496, 2010.

# Weight Optimization of HYDROïD Humanoid Robot

## New methodologies and Advanced material

**M. ELASSWAD, Dr. S.ALFAYAD, Prof. K.KHALIL, Prof. F.B. OUEZDOU**

In the field of robotics, many researchers aim to build a lightweight robotic system, with a high strength and minimum energy consumption. In addition, when talking about humanoid robot, the main target is to have a mechanism with a weight, size and power efficiency similar to human being. However, these aims are found to be contradicting, especially when talking about hydraulic humanoid robots, such as HYDROïD. HYDROïD ($125kg$ and $1.8m$) is the first hydraulic integrated robot, in which the pipes are replaced by internal passages, directly integrated in the mechanical parts. The ultimate target is to reach the capability to achieve hard tasks, with high reliability and accuracy. Despite, its main drawback is that the hydraulic integration needs the employment of high duty metals, in order to hold high pressure. This, inherently generates several issues such as heavy weight, complexity of manufacturing process, high cost and high manufacturing time.

The target is to overcome these challenges and minimize the weight of HYDROïD robot, by decreasing the weight of the hydraulic integrated mechanical parts, which compose about 70 % of HYDROïD. Moreover, most of the hydraulic integrated parts are found in the arms and legs, which gives high weight concentration in the upper and lower parts of the robot. Consequently, lightweight, high strength, high reliability and low cost mechanical hydraulic integrated parts should finally be achieved mainly in HYDROïD arms and legs. Figure 1 presents the HYDROïD integrated hydraulic arm and gives of a survey on integrated hydraulic parts masses.

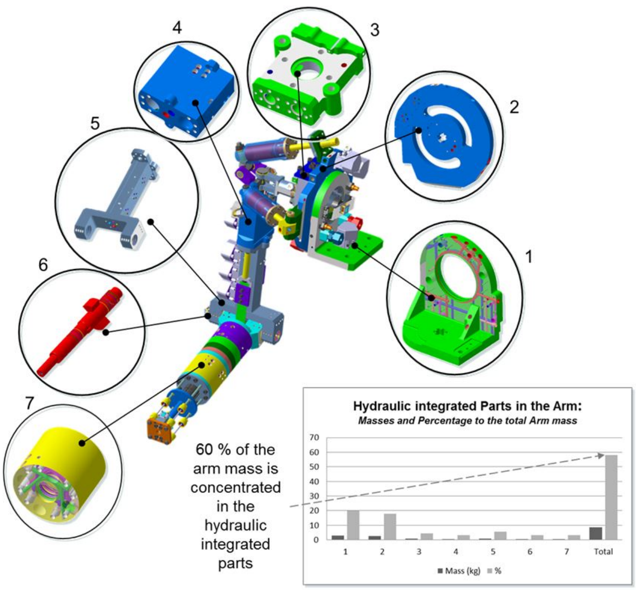



Figure 1: Survey on the arm hydraulic integrated parts masses

Thus, new methodologies are proposed, based on 3D printing technology and composite materials, in order to tackle these drawbacks and bring the HYDROïD mass almost equal to $70kg$. First, more load cases knowledge is obtained using FEM process on the parts. Second, suitable composite materials are chosen according to the stress analysis results and the design parameters. Third, new designs for the internal passages of the parts are carried out respecting the constraints of 3D printing. Moreover, these designs are implemented using 3D printing technology. Meanwhile, random fiber composite is added to fulfill the mechanical properties of the parts. Finally, these parts would be assembled and tested using different mechanical tests method. As example, Figure 2 gives the results on the arm mass reduction ratio which is almost equal to $72\%$ .

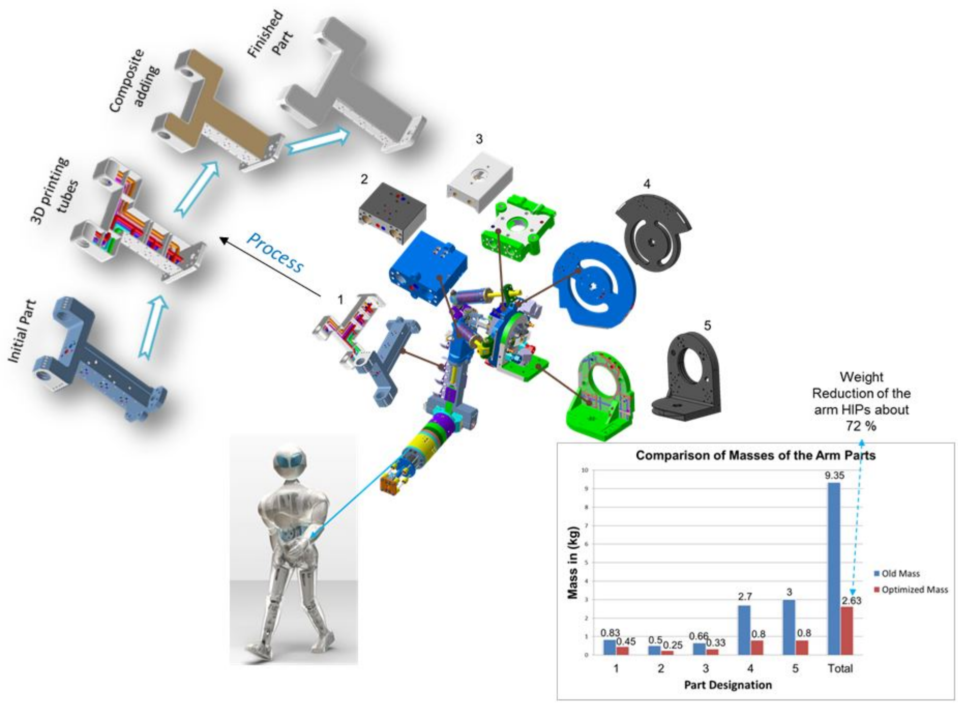
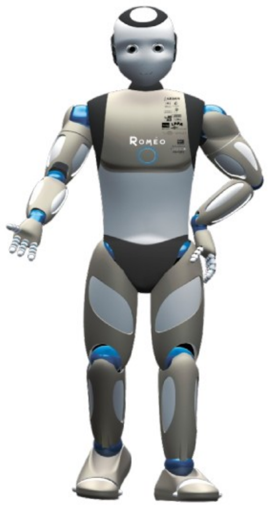



Figure 2: Results of the applied methodology on the arm mass

# Romeo and the Stack of Tasks

Olivier STASSE[1], Nicolas MANSARD[1], Florent FORGET[1], Kevin GIRAUD--ESCLASSE[1]

ROMEO



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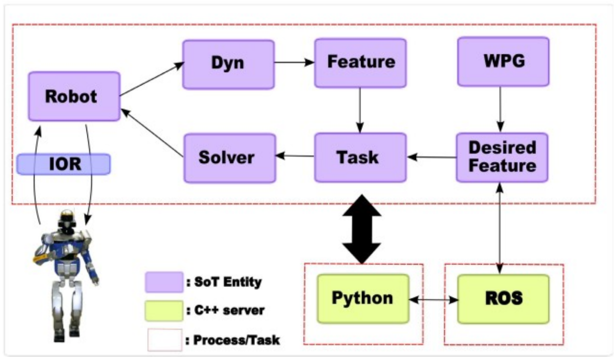
Stack of Tasks




Romeo was made to become a personal companion. The high number of its degrees of freedom together with its complex redundant kinematic chain imply the use of a whole body control framework. Gepetto team realized the Stack of Tasks to tackle whole body motion generation for complex and redundant kinetic chains. It can provide the control of the robot as well as the complex tasks Romeo is expected to accomplish. We will focus on the integration of SOT on the robot and the low level control.

Besides the low available space on the machine and its computing power, the Linux distribution Gentoo is not fully supported by the SOT framework. Furthermore the computation time is crucial to provide an adequate control of the humanoid dynamic. Going through this specificities we will present some implementation results. The mechanical part suffers from flexibility in the cabled actuators. The actual control speed is not sufficient enough, this encourage us to reimplement motorboards firmware in order to identify and command the actuators.

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# GPU-based Semi-Infinite Optimization for Whole-Body Robot Control

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## Abstract

A humanoid robot is a complex system with numerous degrees of freedom, whose behavior is subject to the nonlinear equations of motion. As a result, planning its motion is a difficult task from a computational perspective [1].

In our work, we aim at developing a method that can leverage the computing power of GPUs in the context of optimization-based whole-body motion planning. We first exhibit the properties of the optimization problem, and show that several avenues can be exploited in the context of parallel computing. Then, we present our approach of the dynamics computation, suitable for highly-parallel processing architectures. Finally, we propose a many-core GPU implementation of the motion planning problem. Our approach computes the constraints and their gradients in parallel, and feeds the result to a nonlinear optimization solver running on the CPU. Because each constraint and its gradient can be evaluated independently for each time interval, we end up with a highly parallelizable problem that can take advantage of GPUs [2]. As a result, reduced computation times open the way for the application of this method to model predictive control.

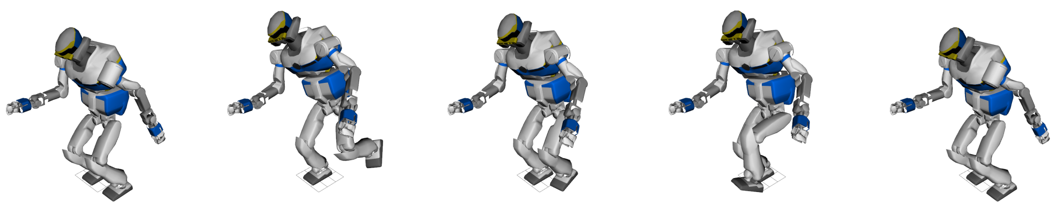

Figure 1: Snapshots from a whole-body motion planning scenario with the HRP-2 humanoid robot. High-level nonlinear tasks can easily be added. Here, the robot achieves a kicking motion with a minimum velocity of 1m/s, while keeping its CoM above its right foot, keeping its right hand fixed in position and orientation under joint position and speed limits. Computation took less than 700 ms with a GeForce GTX Titan Black GPU for that 5-second motion. The optimization problem consists in 336 variables and 1960 constraints.

## References

[1] S. Lengagne, J. Vaillant, E. Yoshida, and A. Kheddar, "Generation of whole-body optimal dynamic multi-contact motions," *The International Journal of Robotics Research*, vol. 32, pp. 1104–1119, apr 2013.

[2] B. Chrétien, A. Escande, and A. Kheddar, "GPU Robot Motion Planning using Semi-Infinite Nonlinear Programming," *IEEE Transactions on Parallel and Distributed Systems*, 2016.

# Dual arm manipulation and whole body control with the humanoid robot Romeo by visual servoing

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## Abstract

The purpose of this presentation is to show two visual-servoing applications on the humanoid robot Romeo: dual arm manipulation and preliminary results on the implementation of a whole body control framework.

In the control scheme for the dual arm manipulation, we consider the case of two arms creating a closed kinematic chain and holding a rigid body object with fixed grasp handles. For this kind of task, common solutions are hybrid force/position control and impedance control. However, if the arms are not equipped with any force sensors, as in our case, an alternative solution is needed. The aim here is to control both arms using a Position-Based Visual Servoing and a master/slave approach, in order to apply any translation and rotation to the grabbed object, just by knowing its pose with respect to the camera. To validate our approach, we developed an augmented reality demonstration. The two arms, 14 joints in total, are holding a tray from two handles as in Figure 1. A known picture is placed on the tray, it is detected automatically and then tracked using the template tracker in ViSP [1]. Furthermore, this algorithm computes the 6D pose of the picture with respect to the camera. A virtual maze is added in augmented reality on the top of the tray and its pose is directly linked with the pose of the picture. The aim of the game is to roll the virtual ball from its actual position to the end of the maze[1]. The main software used to develop this framework are the Aldebaran SDK C++, ViSP, ViSPNaoqi, Panda3D[2], Metapod[3] and OpenCV. The source code of this demonstration is available online on GitHub[4].

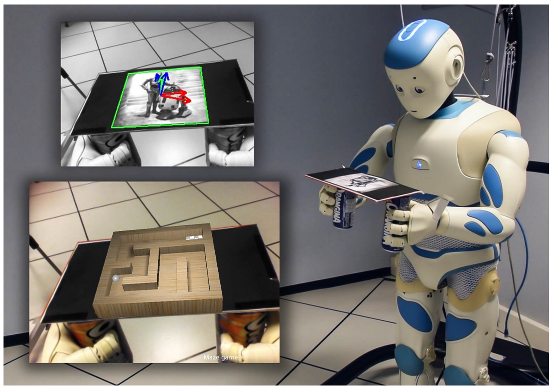

Figure 1: Romeo solves a ball-in-maze game in augmented reality using two hands. Only vision is used to control both arms.

The whole body control framework consists in adapting on Romeo, the multi-objective quadratic program controller presented in [2], which was originally implemented on the HRP-2 robot. Our preliminary results show that visual servoing tasks can be achieved along with common tasks, such as maintaining a posture, balancing and avoiding joint limits. For this purpose, an Image-Based Visual Servoing is used to track the hand with the gaze. Simultaneously, a Position-Based Visual Servoing is used to move the hand from its current position to a desired one, in order to accomplish manipulation tasks, such as grasping. This approach leads to a larger workspace and enables the performance of more complex motions than our previous solution [3].

## Acknowledgement

This work was partly funded by the Oseo Romeo 2 Project.

## References

[1] E. Marchand, F. Spindler, F. Chaumette. “ViSP for visual servoing: a generic software platform with a wide class of robot control skills”, IEEE Robotics and Automation Magazine, Special issue on “Software Packages for Vision-Based Control of Motion”, 12(4):40-52, December 2005, http://team.inria.fr/lagadic/visp

[2] J. Vaillant, A. Kheddar, H. Audren, F. Keith, S. Brossette, A. Escande, K. Bouyarmane, K. Kaneko, M. Morisawa, P. Gergondet, E. Yoshida, S. Kajita, & F. Kanehiro. “Multi-contact vertical ladder climbing with an HRP-2 humanoid”, Autonomous Robots, 2016, 40, 561-580

[3] G. Claudio, F. Spindler, F. Chaumette. “Grasping by Romeo with visual servoing”, Journées Nationales de la Robotique Humanoïde (JNRH), Jun 2015, Nantes, France, <hal-01159882>

[1] Video dual arm manipulation: `https://youtu.be/-wIzJ2Ckifg`
[2] `https://www.panda3d.org/`
[3] `https://github.com/laas/metapod`
[4] `https://github.com/lagadic/`

# Combining visual servoing and walking in an acceleration resolved whole-body control framework

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## Abstract

This work aims to create a solution to executing visually guided tasks on a humanoid robot while taking advantage of its floating base. The base framework is an acceleration-resolved weighted Quadratic Programming approach for whole-body control [1]. This allows us to define different tasks for different control points (i.e., Center of Mass/CoM, hand, gaze) on the robot while respecting constraints (i.e., actuation limits, contacts). In this work, we create visual servoing tasks - specifically a Position-Based Visual Servoing (PBVS) task for the right hand and an Image-Based (IBVS) task for centering the target in the image space. The formulation used is:

$$\ddot{\mathbf{e}} = \mathbf{L_e}\mathbf{J_p}\ddot{\mathbf{q}} + \mathbf{L_e}\dot{\mathbf{J}}_\mathbf{p}\dot{\mathbf{q}} + \dot{\mathbf{L}}_\mathbf{e}\mathbf{J_p}\dot{\mathbf{q}},$$

which is consistent with the acceleration resolved approach for a task vector $\mathbf{e}$, where $\mathbf{L_e}$ is the interaction matrix from visual servoing literature, $\mathbf{J_p}$ is the robot Jacobian of a control point $\mathbf{p}$ and $\mathbf{q}$ are joint positions. The formulation can be used for both PBVS and IBVS simply redefining $\mathbf{e}$ and the corresponding $\mathbf{L_e}$. For walking, we use a walking pattern generator (WPG) similar to [2]. This generates a dynamically consistent CoM motion along with the future footstep locations and timings of foot contact transitions. However, since the WPG is solved separately, we will need a way to couple the WPG reference velocity and the visual servoing tasks. A simple but effective method is setting:

$$\dot{c}_{\mathrm{xref}} = k_v(t_{\mathrm{xPBVS}}), \qquad \dot{c}_{\mathrm{yref}} = 0, \qquad \dot{\theta}_{\mathrm{ref}} = -k_\theta(\theta_{\mathrm{gaze}}),$$

where the WPG input reference velocities are $\dot{c}_{\mathrm{xref}}, \dot{c}_{\mathrm{yref}}, \dot{\theta}_{\mathrm{ref}}$, while $t_{\mathrm{xPBVS}}$ is the translation part of the hand PBVS task corresponding to the $x$ axis of the WPG frame (local frame on the robot), $\theta_{\mathrm{gaze}}$ is the yaw angle of the gaze frame relative to the current WPG frame and $k_v, k_\theta$ are gains to tune. The idea is that the hand PBVS will guide walking forward. Walking sideways is not used. The orientation is guided by the gaze IBVS. Finally, note that bounds are needed for $t_{\mathrm{xPBVS}}$ and $\theta_{\mathrm{gaze}}$ that are used in the coupling. When a bound is exceeded, we use: $\mathbf{e}' = \frac{\mathbf{e}}{\max(\mathbf{e})}$ where $\mathbf{e}$ is the unbounded error, $\max(\mathbf{e})$ is the largest limit violation and $\mathbf{e}'$ is the result used. This preserves the vector direction. We validated this approach with simulations using the HRP-4 robot. Screenshots are shown below:

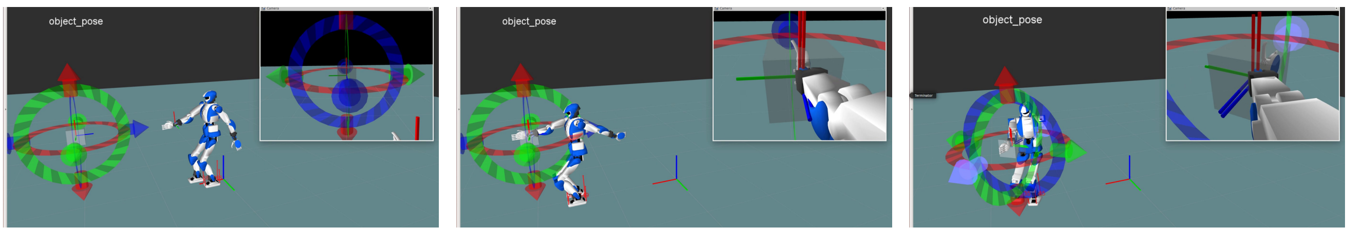


Figure 1: Example screenshots of a simulation of positioning the hand and gazing the target

## Acknowledgement

This work is supported in part by the Horizon H2020 program COMANOID (www.comanoid.eu).

## References

[1] J. Vaillant, A. Kheddar, H. Audren, F. Keith, S. Brossette, A. Escande, K. Bouyarmane, K. Kaneko, M. Morisawa, P. Gergondet, E. Yoshida, S. Kajita, and F. Kanehiro, "Multi-contact vertical ladder climbing with an HRP-2 humanoid," *Autonomous Robots*, vol. 40, no. 3, pp. 561–580, 2016.

[2] A. Herdt, H. Diedam, P.-B. Wieber, D. Dimitrov, K. Mombaur, and M. Diehl, "Online walking motion generation with automatic footstep placement," *Advanced Robotics*, vol. 24, no. 5-6, pp. 719–737, 2010.

# Motion Generation for Pulling a Fire Hose by a Humanoid Robot

Ixchel G. Ramirez-Alpizar[1], Maximilien Naveau[2], Christophe Benazeth[2], Olivier Stasse[2], Jean-Paul Laumond[2], Kensuke Harada[1], and Eiichi Yoshida[3]

## Résumé

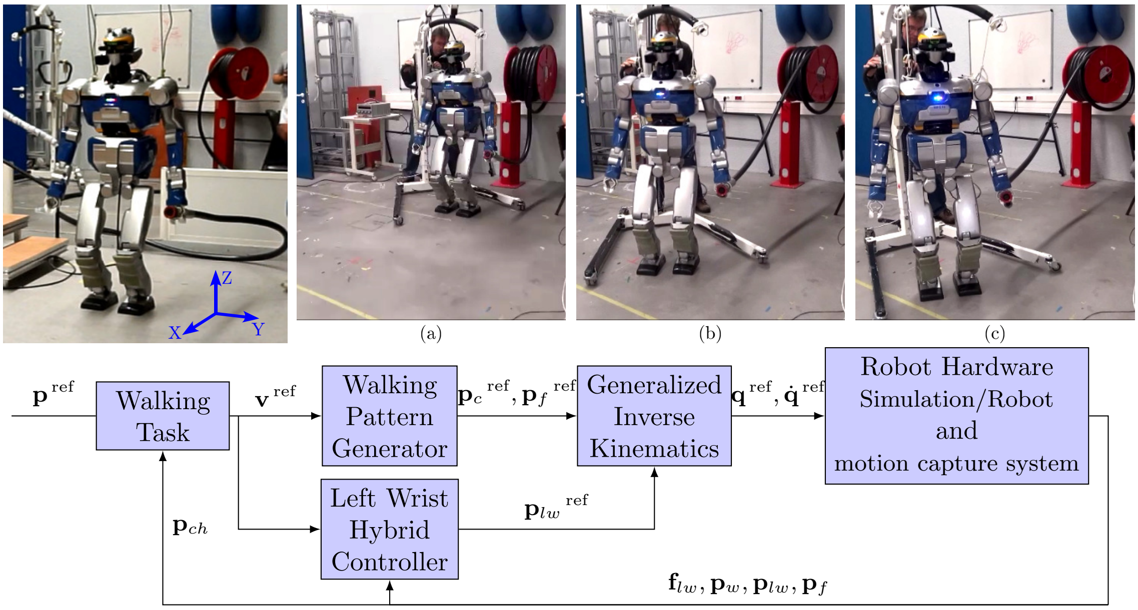


FIGURE 1 – First picture depicts the system coordinates. Second set of picture show the drift induced by the hose without any specific controller : 90 degrees in 1 meter. Third picture the controller used to counteract this drift.

This paper discusses a strategy for a humanoid robot to pull a fire hose while walking towards a desired position and orientation. First of all, we used motion planning for picking the fire hose from the floor. Then, a hybrid controller on the robot's wrist holding the fire hose is implemented for pulling it. The proposed controller can automatically determine the pulling force according to the robot's walking velocity.

Through simulation analysis and experiment it is shown that when the robot walks while pulling forward the fire hose a significant drift in the walking direction is generated (see Figure 1 a,b,c). To cope with this drift and to direct the robot to a desired position and orientation, a walking task is introduced. Using a motion capture system, the robot's chest position and orientation is monitored and feed to the robot's walking pattern generator to correct the orientation drift and to determine where to walk and when to stop walking. Through experimental results the validity of the proposed strategy was confirmed. The global strategy is summarized in Figure 1 feedback scheme. Finally, we show that the proposed hybrid controller contributes to the improvement of the robot's balance when walking.

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[2] M. Naveau, C. Benazeth, O. Stasse and J.-P. Laumond are with CNRS, LAAS, Université de Toulouse, 7 avenue du Colonel Roche, F-31400, Toulouse, France. {mnaveau, benazeth, ostasse, jpl}@laas.fr

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# A versatile and efficient framework for multi-contact legged locomotion

Steve Tonneau and Justin Carpentier

May 26, 2016

We present a versatile and efficient framework capable of planning and executing acyclic motions for legged robots by exploiting contacts. Such complex motions (standing up, climbing stairs using a handrail) are hard to compute because they involve non coplanar contacts and non gaited locomotion patterns, which introduce a combinatorial. Our framework answers a need raised at the DARPA Robotics Challenge, where the lack of an automatic acyclic contact planner was recognized as a major issue.

The key contribution of our framework is the computation time of the complete motion, reduced to a few seconds, making it compatible with a model predictive control approach. Such efficiency is achieved with significant contributions on both the planning and optimization levels of the framework.

The framework is a two stages approach:

- in a first phase, without requiring prior knowledge, a sampling based planner is used to automatically compute a discrete sequence of static equilibrium contact configurations.
- in a in a second phase, we compute a dynamically consistent trajectory for the centroidal dynamics of the robot, composed of the linear and angular momenta. This trajectory follows the discrete contact sequence and satisfies the wrench constraints.

The interest of the method is demonstrated by real experiments on the HRP-2 robot, by performing long-step walking, climbing a staircase with handrail support and a standup motion.

# Zones de support du ZMP
# pour la locomotion multi-contact

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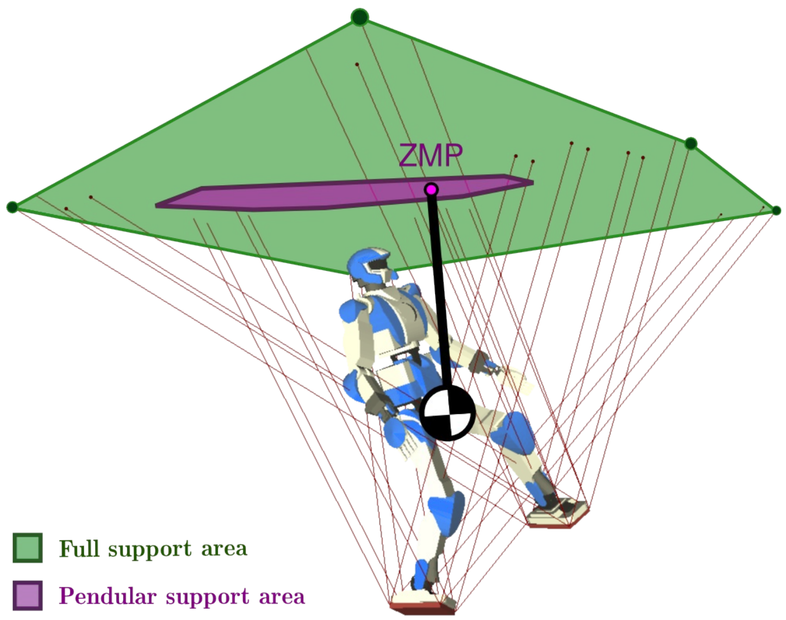
## Résumé

Le Zero-tilting Moment Point (ZMP) et son polygone de support sont les deux notions qui permirent aux roboticiens de résoudre le problème de la marche sur sol horizontal. Leur définition historique présente malheureusement deux limitations de taille : tous les contacts entre robot et environnement doivent être coplanaires, tandis que les glissements ou rotations de lacet ne sont pas pris en compte. Nous présentons ici une construction générale de la « zone de support » du ZMP qui s'affranchit totalement de ces deux limites. Nous montrons ensuite comment l'appliquer avec une loi de contrôle de type pendule-linéaire pour générer des trajectoires locomotrices humanoides dans un environnement où les contacts sont disposés arbitrairement dans l'espace.




## Bio

Né en 1988 à Toulouse, Stéphane Caron a étudié à l'École Normale Supérieure (rue d'Ulm). Après un séjour d'un an au Technicolor Lab. de Palo Alto (Californie), il s'est engagé dans la recherche en robotique par un doctorat au Nakamura Lab. de l'Université de Tokyo (Japon). Sa thèse a porté sur la planification du mouvement pour les robots humanoïdes, et plus particulièrement sur la gestion de l'équilibre et des contacts. Stéphane est actuellement chercheur post-doctoral au Laboratoire d'Informatique, de Robotique et de Microélectronique de Montpellier (LIRMM).

## Ressources

Pre-print: http://arxiv.org/abs/1510.03232
Slides: https://scaron.info/research/laas-2016.html

# Commande de gestion d'équilibre pour un exosquelette de jambes

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## Résumé

De nos jours, les exosquelettes se développent de plus en plus, que ce soit dans le domaine du militaire, de l'industrie (Hv3) ou du médical (Rewalk). Quelle que soit l'application, la question de la stabilité posturale – de l'équilibre – se pose dans les mouvements de marche, les transferts de position et les stations statiques. Jusque-là, la stabilisation du système couplé {homme+machine} est assurée par l'utilisateur et éventuellement des béquilles. Mais l'augmentation de la charge transportée et de l'inertie, ainsi que l'activité même de l'exosquelette, rendent cette stabilisation difficile.

Nous proposons une commande qui s'inspire des stratégies de récupération d'équilibre chez l'humain et qui va permettre de l'assister en cas de besoin. Elle ne prend en compte que l'exosquelette et non le système entier couplé {opérateur + exosquelette} : comment l'exosquelette réagit il face à des perturbations externes que nous pouvons considérer provenant de l'opérateur. Pour décrire le comportement global de l'exosquelette, on utilisera un modèle très largement utilisé dans le domaine de la bipédie, le modèle du pendule inversé linéarisé : on étudiera le comportement d'un point nommé le point de capture pour détecter une situation de déséquilibre et on tentera de le contrôler et de gérer la répartition des efforts sur chaque jambe pour rendre le système stable.

## Références

**D.A. Winter**. Human balance and posture control during standing and walking. *Gait and Posture*, 1995.

**A.L. Hof, M.G.J. Gazendam, and W.E. Sinke**. The condition for dynamic balance. *Journal of Biomechanics*, 2004.

**J. Englsberger, C. Ott, M.A. Roa, A. A-Schaffer, and G. Hirzinger**. Bipedal walking control based on capture point dynamic. *IEEE International Conference on Intelligent Robots and Systems*, 2011.

**T. Koolen, T. de Boer, J. Rebula, A. Goswami, and J. Pratt.** Capturability-based analysis and control of legged locomotion, part 1 : Theory and application to three simple gait models. *The International Jounal of Robotic Research*, 2012.

**J. Pratt, T.Koolen, T. de Boer, J. Rebula, S. Cotton, J.Carff, M. Johnson, and P. Neuhaus**. Capturability based analysis and control of legged locomotion, part 2 : Application to m2v2, a lower-body humanoid. *The International Jounal of Robotic Research*, 2012.

# Stratégie de chute et réglage de gains en temps-réel

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## Résumé

L'étude menée a pour but d'établir une commande lors de la chute d'un robot humanoïde lorsque celle-ci est inévitable. L'année dernière, nous avons détaillé une taxonomie de chutes [1] et donné une commande basée sur la géométrie pour "atterrir" dans les conditions les moins à risque pour le robot. Cet "atterrissage" est accompagné d'un changement des gains PD de la commande bas niveau des moteurs. Notre expérience (voir Figure 1) montre les résultats pour des chutes frontales et arrières. Depuis, nous avons établi quelques méthodes pour des chutes dans des environnements complexes et pouvant prendre en compte des chutes latérales. Enfin, nous travaillons sur le calcul en temps réel de gains optimaux à donner aux moteurs pour absorber l'impact à la chute ce qui permet de réduire les risques de destruction des moteurs.

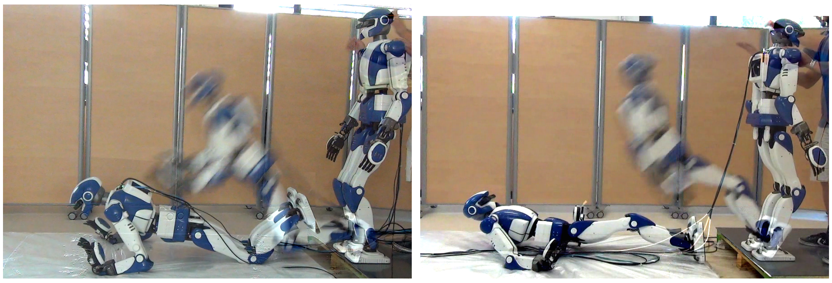

Figure 1 – Chute du HRP4 après avoir été poussé.

## References

[1] SAMY, Vincent et KHEDDAR, Abderrahmane. Falls control using posture reshaping and active compliance. In: Humanoid Robots (Humanoids), 2015 IEEE-RAS 15th International Conference on. IEEE, 2015. p. 908-913.

# Attitude Estimation and Stabilization of a Compliant Humanoid Robot Using Only Inertial Measurement Units

A. Mifsud[1], M. Benallegue[2], F. Lamiraux[1]

## Résumé

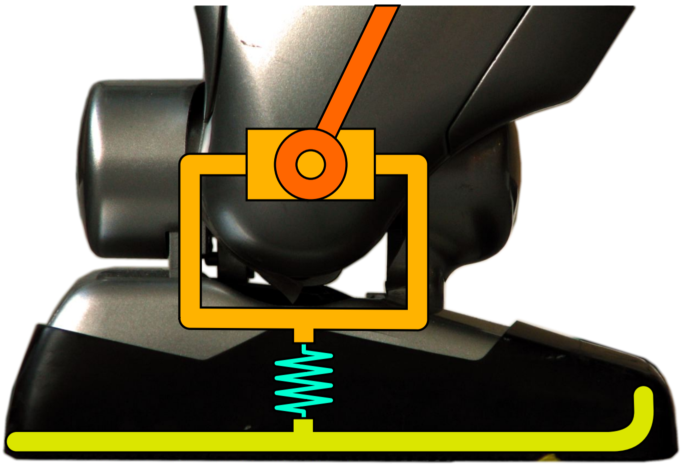

FIGURE 1 – The foot of HRP-2. Between the ankle joint and the sole of the robot, there is a rubber bush.

A humanoid robot is underactuated and only relies on contacts forces to move in the space and maintain balance. Constraints on contact forces have then to be respected to guarantee this balance. This is the goal of the stabilizer. To do this, controllers usually consider the robots as totally stiff and there joints positions perfectly known. However, several robots contain compliant parts in their structure, for example at contacts. This flexibility modifies the forces at contacts and endangers balance. Moreover, most controllers relies on force sensors to predict the robot dynamics including balance. In other hand, several humanoid robots are not equipped with these sensors which are expensive and sensitive to calibration errors. In this article we will show how it is possible to use a model of the flexibility dynamics and an IMU to estimate contact forces without using force sensors. We will then show how we can use this information to build a stabilizer which relies only on IMU sensors. We show that we are able to reconstruct efficiently the position of the Center of Pressure (CoP) of the robot with only the IMU and proprioceptive data from the robot. Experimental results on HRP-2 robot show that the stabilization successfully rejects perturbations with high gains using only these IMU signals.

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# Comment la forme des trajectoires locomotrices révèle le rôle de la vision


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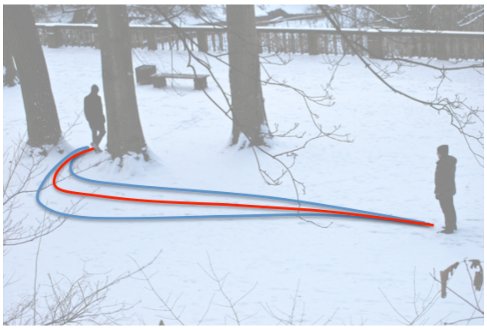
Cet exposé porte sur un problème de commande optimale inverse appliqué à l'identification d'un critère permettant d'expliquer la forme des trajectoires locomotrices humaines. On verra en particulier l'importance du choix de la base de fonctions à partir de laquelle s'exprime la fonction de coût, comment des critères quadratiques sur les commandes constituent de mauvais choix, et comment l'angle de gisement est amené à jouer un rôle particulier.

Cet exposé prend appui sur un travail récent conduit en commun avec K. Mombaur et M. Sreenivasa de l'Université d'Heidelberg.

*M. Sreenivasa, K. Mombaur, J.P. Laumond, Walking paths to and from a goal di_er : On the role of bearing angle in the formation of human locomotion paths. PlosOne, Vol. 10, N. 4, 2015.*




$$\begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \\ \dot{v} \\ \dot{v}_\perp \\ \dot{\omega} \end{pmatrix} = \begin{pmatrix} v.\cos\theta - v_\perp.\sin\theta \\ v.\sin\theta + v_\perp.\cos\theta \\ \omega \\ 0 \\ 0 \\ 0 \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ 0 \end{pmatrix} u_1 + \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \end{pmatrix} u_2 + \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix} u_3$$

$$L(u) = (\alpha_0 + \alpha_1 u_1^2 + \alpha_2 u_2^2 + \alpha_3 u_3^2)dt$$

# Exploring Walking Patterns of Cerebral Palsy Children by Numerical Simulation

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Cerebral Palsy is the most common cause of pathological gait among children, affecting 1 newborn over 450 each year in France. The gait abnormalities presented by those children are usually the result of four kinds of impairments: spasticity, muscle contracture, weakness and bone deformities. Compensatory mechanisms may also occur. Those different causes can be addressed by different treatments (physiotherapy, botulin toxin, orthotics, surgery, etc.). In order to choose the best strategy, the underlying causes of the locomotion disorders must be first clearly identified.

In [1] we present a framework to generate different gait patterns, taking into account the variety of contacts presented by children with cerebral palsy. It results of an extension of the work of [2]. A numerical manikin is designed based on the anthropomorphic characteristics of the children [3], and articulated feet are considered. Three types of walking can be simulated:

- Equinus Gait, walking with only the forefeet touching the ground;
- Flat Feet Gait, the standard robot gait;
- Walking with a Heel Rocker, as in human normal gait.

Using analysis techniques like cyclograms or phase portraits, variability and complexity between these types can be assessed [4]. This procedure allows to test different perturbation scenarios, like restrained joint mobility, and to explore its effect on the gait pattern.

Having a numerical tool to explore locomotion patterns and disorders can help to better understand the mechanisms behind them. Being able to numerically identify the causes of pathological walking can help to improve treatment planning.

**References:**

[1] A. P. Santos, F. Ben Amar, P. Bidaud, and E. Desailly, "Gait synthesis for an anthropomorphic human model with articulated feet," *Comput. Methods Biomech. Biomed. Engin.* pp. 1–2, Aug. 2015.

[2] J. Salini, V. Padois, and P. Bidaud, "Synthesis of Complex Humanoid Whole-Body Behavior: a Focus on Sequencing and Tasks Transitions," in *Proceedings of the IEEE International Conference on Robotics and Automation*, Shanghai, China, 2011, pp. 1283–1290.

[3] R. Dumas, L. Chèze, and J.-P. Verriest, "Adjustments to McConville et al. and Young et al. body segment inertial parameters," *J. Biomech.*, vol. 40, no. 3, pp. 543–553, Jan. 2007.

[4] K. S. Rosengren, F. J. A. Deconinck, L. A. DiBerardino, J. D. Polk, J. Spencer-Smith, D. De Clercq, and M. Lenoir, "Differences in gait complexity and variability between children with and without Developmental Coordination Disorder," *Gait Posture*, vol. 29, no. 2, pp. 225–229, Feb. 2009.

# How do walkers avoid a mobile robot crossing their way?


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## Abstract

Robots and Humans have to share the same environment more and more often. In the aim of steering robots in a safe and convenient manner among humans it is required to understand how humans interact with them. This work focuses on collision avoidance between a human and a robot during locomotion. Having in mind previous results on human obstacle avoidance, as well as the description of the main principles which guide collision avoidance strategies, we observe how humans adapt a goal-directed locomotion task when they have to interfere with a mobile robot. In particular, we have investigated the reactions in case the obstacle is passive or cooperative, exploiting human avoidance strategies previously observed.


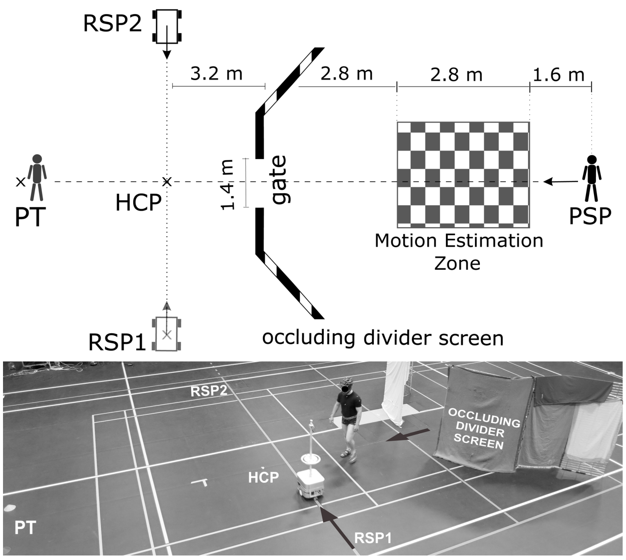


FIGURE 1 – Illustration of the experimental apparatus and task. In this trial the robot was moving from RSP1 to RSP2.

**Participant Task**: They were asked to walk at their preferred speed from PSP to PT by passing through a gate. They were told that a robot would be moving in the area located on the other side of the gate that could interfere with their trajectory. One experimental trial corresponds to one travel of the participant from the starting position to the target.
**Robot Behaviour**. We programmed the robot to execute a trajectory between the two positions RSP1 and RSP2. The robot is controlled to generate specific interactions with the participant. In case of *passive behaviour*, the robot moves along a straight line at constant speed ($1.4m.s-1$). We wanted the robot either to be: a) on a full collision course (reach HCP at the same time than the participant), b) on a partial collision course (the robot reaches HCP slightly before or after the participant), or c) not on a collision course. In case of *cooperative behavior*, the robot moves with the same velocity as the actor. When the actor is near to pass through the gate, the robot predicts the future collision and decides whether to give the way (decelerate and pass behind the actor) or pass as first (accelerate and pass in front of the actor). To this end, we measure the participant gait speed through MEZ and estimate the future collision configuration.
**Results**. We observed that collision avoidance between a human and a robot has similarities with the case of two humans crossing each other (estimation of collision risk, anticipation) but also leads to major differences. In case the robot is passive, humans preferentially give way to the robot, even if this choice is not optimal with regard to motion adaptation to avoid the collision. We interpreted this behavior based on the notion of perceived danger and safety. However when the robot is cooperative, the actors preserve human-human avoidance strategies eliding the differences observed during human-robot interactions.

# Energetic Comparison of Spring Mass Model and Poly-Articulated Model during human gait

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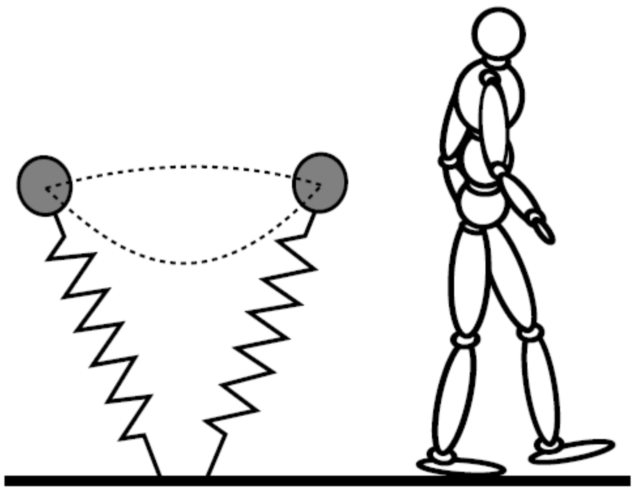
The human is often modeled as a Poly-Articulated Model (PAM) with rigid segments while some authors use a Spring Mass Model (SMM) for modeling locomotion. These two models are considered independent, and the objective of this study was to link them in order to enlighten the role of elasticity in locomotion.

Using the characteristics of the two models, a theoretical relationship demonstrates that the variation of elastic energy of the SMM equals the variation of the internal kinetic energy minus internal forces work of the PAM. This theoretical relationship was experimentally investigated among 19 healthy participants walking and running on a treadmill.

The results showed that the equality is verified during the first half of the stance phase. However, differences were observed between the variation of elastic energy (SMM) and the variation of the internal kinetic energy minus internal forces work (PAM) from the midstance to the contralateral heel strike during walking and running.

The formal relationship showed that the global stiffness of the SMM is directly related to the work of the internal forces of the PAM, and thus, to the characteristics of the musculoskeletal system. It also showed the relevance of taking into account the participation of each joint in the global stiffness. Finally, the coordination of internal forces work to produce a global stiffness may be considered as a new criterion of movement optimization for clinical purposes or motion planning for humanoid robots.

**Keywords:** Elastic energy, work of internal forces, mechanical energy theorem, energy transfers, human gait



Spring Mass Model (SMM) and Poly-Articular Model (PAM) including 16 segments used for walking and running gaits.

**Bibliography:**

Moretto P., Villeger D., Costes A., Watier B.: Elastic Energy in Locomotion: Spring-Mass vs. Poly-Articulated Models. Gait and Posture, In press, 2016.

# Evaluation of an inverse KKT approach on a human walking task

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Inverse optimal control (IOC) can offer a good understanding on some of the principles on which the human motor control (HMC) works in a control theory framework. This problem aims at identifying which criteria are minimized by the HMC while doing a certain motor task, under the assumption that the actual data are a given solution of an optimal control problem. Moreover, it is assumed that the motion-captured human demonstrations are in accordance with what the HMC is planning. IOC can be used to design adequate controllers, which can be used to create robust and dynamic robot behaviors, by optimizing the trajectory with respect to these objectives.

In our study, we would like to report on the evaluation of an inverse optimal control approach based on inverse Karush-Kuhn-Tucker (KKT) used with parameterized Lagrangians [3-5], to analyze and infer criteria from human walking demonstrations. One can also find other available methods, such as the bi-level approach [1], which can also be reduced to a "generalized bi-level" approach [2]. The inverse KKT approach reduces the optimization problem to a least square problem, easier to solve and with the advantage of nice computation time. The exhibited computational time encouraged us to dig deeper into the methodology being interested to use them in the future for online applications. This approach was recently used to obtain robots capable of opening doors or sliding a box [4] or to control prosthetic devices [5].

We first address ways of solving the ill-posedness of the IOC by means of normalization methods, to avoid undesired trivial solutions. Second, we discuss, in the optimal control framework, the biomechanics component of the closed-loop model of gait initialization in subjects during walking tasks. Our closed-loop model will use a model predictive control (MPC) scheme, as suggested by [6], capable of synthesizing both the kinematics and dynamics of the center of mass (CoM), of the center of pressure (CoP), and of feet placement and step duration during the first two steps. The 2D-sagittal and horizontal planes (with the assumption that the CoM height is constant on the horizontal plane) – dynamical system are those of a running cart on a table [7]. Finally, we learn costs from human demonstrations, and capture features of the desired behavior, along with locomotion trajectories and step parameters that resemble the original human demonstration within a couple of minutes.

**References**

[1]. K. Mombaur, A. Truong, and J.-P. Laumond, *From human to humanoid locomotion—an inverse optimal control approach*, Autonomous Robots, vol. 28, pp. 369–383, 2010.

[2]. S. Albrecht, K. Ramirez-Amaro, F. Ruiz-Ugalde, D. Weikersdorfer, M. Leibold, M. Ulbrich, and M. Beetz, *Imitating human reaching motions using physically inspired optimization principles*, 2011 11th IEEE-RAS International Conference on Humanoid Robots, Oct 2011.

[3]. A. V. Papadopoulos, L. Bascetta, and G. Ferretti, *Generation of human walking paths*, Autonomous Robots, Jun 2015.

[4]. P. Englert and M. Toussaint, *Inverse kkt - learning cost functions of manipulation tasks from demonstrations*, in Proceedings of the International Symposium of Robotics Research, 2015.

[5]. N. Aghasadeghi and T. Bretl, *Inverse optimal control for differentially flat systems with application to locomotion modeling*, in Robotics and Automation (ICRA), May 2014, pp. 6018–6025.

[6]. A. Herdt, H. Diedam, P.-B. Wieber, D. Dimitrov, K. Mombaur, and M. Diehl, *Online Walking Motion Generation with Automatic Foot Step Placement*, Advanced Robotics, vol. 24, no. 5-6, pp. 719{737, 2010.

[7]. S. Kajita, F. Kanehiro, K. Kaneko, K. Fujiwara, K. Harada, K. Yokoi, and H. Hirukawa, *Biped walking pattern generation by using preview control of zero-moment point*, in IEEE International Conference on Robotics and Automation, vol. 2, pp. 1620-1626, september 2003.

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# Trajectoires inspirées par la loi de puissance 1/3 pour le robot humanoïde HRP-2.

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## Résumé

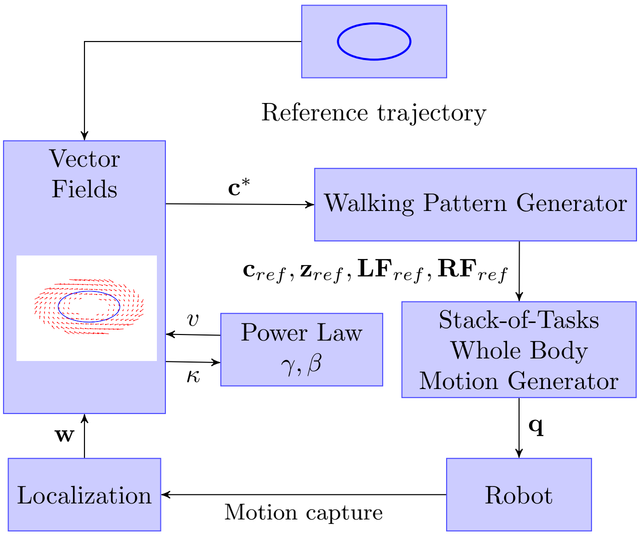


FIGURE 1 – Overall control scheme to make HRP-2 walks along ellipsoidal trajectories

La loi de puissance 1/3 est un modèle de l'évolution de la vitesse de la marche de l'être humain qui dépend de la courbure de la trajectoire suivie. Dans le cadre de ce travail nous avons étudié l'intérêt d'utiliser cette loi pour un robot humanoïde suivant une trajectoire de référence comme illustré dans la Figure 1. Le comportement de cette loi impose au robot de ralentir dans les passages avec une grande courbure et d'accélérer dans les passages sans courbure. Intuitivement un robot humanoïde qui suivrait une trajectoire de référence suivant la loi de puissance 1/3 devrait réduire les problèmes de suivi et l'énergie consommée. Afin de gérer les glissements possibles sur le sol, nous avons utilisé des oscillateurs d'Andronov-Hopf contractants pour régulariser la trajectoire du robot afin de converger vers une trajectoire planifiée cyclique. Le générateur de motif de marche utilisé sur HRP-2 suit cette dynamique pour marcher sur des trajectoires dynamiques. En simulation dynamique, nous avons observé un décalage spatiale minimale avec la loi de puissance 1/3, comparée avec le modèle à vitesse constante, et les autres puissances. Des expériences sur le robot réel contrôlé en boucle fermée donne des décalages faibles sur toutes les puissances, ce qui démontre l'efficacité du contrôle. Nous avons observé que la puissance 1/3 demande moins d'actions compensatrices et par conséquent minimize l'énergie sur le robot. De plus le temps d'exécution du mouvement est plus rapide.

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