2007 IEEE International Conference on
Robotics and Automation
Roma, Italy, 10-14 April 2007

Integrating Walking and Vision to Increase Humanoid Robot Autonomy

Olivier Stasse[1], Björn Verrelst[2], Andrew Davison[3], Nicolas Mansard[4], Bram Vanderborght [2]
Claudia Esteves[5], François Saidi,[1], Kazuhito Yokoi[2]
[1] *JRL, AIST-CNRS, ISRI, Tsukuba, Japan*
E-Mail : {olivier.stasse,francois.saidi, kazuhito.yokoi}@aist.go.jp
[2] *University of Bruxelles, Belgium E-Mail :* { bjorn.verrelst, b.vanderborght}@vub.ac.be
[3] *Imperial College of London, United Kingdom E-Mail :* adj@doc.ic.ac.uk
[4] *IRISA - INRIA Rennes, France E-Mail :* nmansard@irisa.fr
[5] *JRL, CNRS-AIST, LAAS, Toulouse, France E-Mail :* cesteves@laas.fr

Abstract— **This video demonstrates our current investigation in developing autonomous behaviors for humanoid robots. Our main goals is to develop functionalities as much generic as possible in order to realize useful behaviors. More particularly this video demonstrates our current status on extending a popular Zero Momentum Problem (ZMP) preview control based pattern generator, and building some links between walking with vision.**

I. Introduction

The first video segment shows a behavior of dynamic stepping over *large* obstacles. It is dynamic in the sense that the robot performs this while dynamically walking. The key point to perform such action is to lower the height of the waist, which goes into contradiction with one of the assumption leading to the construction of the pattern generator. The second segment shows how it is possible to exploit further this possibility. Indeed it allows the humanoid robot to handle a 2m meter bar and go through a door too small for his size. This is achieved through the help of vision and planning. The third segment illustrate how monocular SLAM can be helped by introducing the information provided by the pattern generator. The fourth segment shows that by using a prioritarized stack of tasks, it is possible to realize a visually-based grasping while walking. The pattern generator is here coherently integrated as a task.

II. Pattern Generator

The pattern generator is based on the work of Kajita and al. [2]. The main idea is to model the robot as the 3D Linear Inverted Pendulum and assume that his Center of Mass (CoM) evolves on a plane. Using this model, the ZMP referenced values can be easily choose from the foot positions, and the CoM trajectory can be computed by solving an inverse problem. This trajectory using simple inverse kinematics allows to compute the joint values for the legs. The upper body's joint values can be choose following other criteria for which some of them are introduced below. Considering all those trajectories together it is possible to compute the ZMP associated to the robot's multibody model by direct dynamics computation. In order to compensate for the discrepancies generated by approximating the robot as a pendulum, Kajita introduced a second preview control.

Also it is possible to modify the height of the CoM, this one has to be constrained on a plane. For some motions, this might be too constraining. We therefore tested numerically and experimentally the robustness of the second filter regarding perturbation of the height's CoM. Setting the preview control for an horizontal motion of the CoM, the system has shown impressive robustness against strong vertical perturbations as big as 20 cm. The first two video segments illustrates our use of those capabilities to perform useful behaviors for a humanoid robot: stepping over large obstacles and going through door while manipulating a bar.

III. CoM's Height modification for stepping over large obstacles

In the first video segment we show how the robot successfully cleared dynamically large obstacles : 10 cm by 5 cm, 15 cm by 5 cm, 10 cm by 10 cm (obstacle's width and height respectively). The methods is based on the modification of the height described previously. It is necessary to find a kinematic configuration allowing to avoid obstacles with a sufficient margin, and this height modification extend the size of the feasible obstacles.

The main practical limitation of the approach presented in [8] is due to the stabilizer commercially available on the robot. Indeed for high obstacles, the swing leg is close to a stretch position. The current stabilizer is sending high accelerations near this position of the swing leg, and those accelerations are not allowed by the low-level security mechanisms embedded inside the robot [8].

IV. CoM's Height modification with 3D reconstruction and planning

The second video segment is presenting our preliminary experiment using the new degree of freedom corresponding to possible variation of the CoM's height. The robot is facing an opening 2 meters far away with an other behind at 4 meters. The goal is to cross the door while manipulating a 2 m long bar hold in the right hand. The environment was reconstructed by using the embedded stereoscopic vision system using previous work [7]. In short, several dense maps were accumulated in a map. The result has been then processed and given as an entry to KineoWorks a general 3D planner [3]. Kineoworks search and optimized the configuration space of a HRP-2 reduced model. In the reduced model the legs are viewed as a bounding box with three degrees of freedom: two in the horizontal plane, and one small translation at the top of the box for the height modification. The upper torso is kept complete. In the present experiment, the optimization was **not** done taken into consideration dynamics. It was assumed that the pattern generator will compensate for the variation introduced by the upper body. Of course, this hypothesis is not valid in the general case. However the range of acceptance of the system is wide, and when this hypothesis is valid it provides a faster solution. It should be noted that as this work is in its early stage, the planning phase has been done off-line. The result is a set of configuration for the upper body according to the position of the waist. The corresponding file is then loaded inside the pattern generator, and the trajectory of the foot and the waist are generated on-line as for the previous experience.

V. SLAM together with Pattern Generator Information

The third video segment present our work on using the information provided by the pattern generator into a monocular SLAM system. The 3D frame illustrates the trajectory of the camera after integrating vision and walking pattern generator information. A key point of the presented system is its capability to "close the loop", i.e. to increase its precision by seeing again the same landmarks when returning to a previous location. The core work related to SLAM has been proposed by Davison in [1]. In [6] we described precisely the experimental context and the current limitation of the system (number of landmarks, size of the environment). The main interest in introducing the pattern generator information inside the Kalman filter is to get rid of the initialization phase mandatory in the original work. Indeed to guarantee the scale of the reconstructed information 4 landmarks were necessary. As an accurate estimate of the true motion is provided by the pattern generator model, those landmarks are not necessary.

VI. Visually-Guided Grasping while Walking on a Humanoid Robot

The fourth segment present an experiment of grasping while walking, The object to grasp is the pink ball, that is estimated using the robot stereoscopic head. This experiment is a mean to investigate two kinds of problems: generating whole-body motion with visual feedback, and organizing tasks to perform several behaviors at the same time. The details of this work, presented also as a full paper to this conference, relies on a previous work proposed by Mansard in [4][5]. In the present experiment several tasks such as image centering, gripper orientation, gripper position, walking are integrated together in a stack of tasks with prioritization. A high-level mechanisms allow to remove and insert tasks. It is ensured that the transition due to the those operations at the velocity level are performed smoothly. Finally the pattern generator has been coherently inserted inside the stack of tasks. It has the highest priority and thus the formulation of the other tasks have been extended to take it into account.

Because preview control need to know the future, it is not possible to include the visual-servoing command into the pattern generator. Following the same line than the other experiments, we have used the left arm to limit the disturbances of the CoM trajectory induced by the tasks execution. However this heuristic is not general.

VII. Conclusion

This video shows our work into building fundamental blocks to increase the autonomy of humanoid robots. We have experimentally investigated the limit of the popular pattern generator proposed by Kajita onto the HRP-2 humanoid robot platform. The extension developed have been integrated the subsequent extension into one software. This has been the basis to build visually-based behaviors demonstrated in this video.

Acknowledgment

The authors would like to thank the Japanese Society for the Promotion of Science for partial funding of this work.

References

[1] A. J. Davison. Real-time simultaneous localisation and mapping with a single camera. In *International Conference on Computer Vision, Nice*, pages 1403–1410, 2003.

[2] 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 *International Conference on Robotics And Automation, Taipei Taiwan*, pages 1620–1626, September 2003.

[3] J.P. Laumond. Kineocam: A success story of motion planning algorithms. *IEEE Robotics & Automation Magazine*, 13(2):90–93, June 2006.

[4] N. Mansard and F. Chaumette. Tasks sequencing for visual servoing. In *International Conference on Intelligent Robots and Systems, IROS*, pages 992–997, Sendai, Japan, november 2004.

[5] Nicolas Mansard and François Chaumette. Visually-guided grasping while walking on a humanoid robot. *IEEE Transactions on Robotics and Automation (to appear)*, 2006.

[6] O. Stasse, A.J. Davison, R. Sellaouti, and K. Yokoi. Real-time 3d slam for humanoid robot considering pattern generator information (accepted). In *International Conference on Intelligent Robots and Systems, IROS, Beijing, China*, October 2006.

[7] O. Stasse, J. Semere, E.S. Neo, T. Yoshimi, and K. Yokoi. Vision-based virtual information and semi-autonomous behaviours for a humanoid robot. In *International Conference on Intelligent Autonomous Systems*, pages 794–803, Tokyo, Japan, March 7-9 2006. IAS.

[8] Bjorn Verrelst, Kazuhito Yokoi, Olivier Stasse, Hitoshi Arisumi, and Bram Vanderborght. Mobility of humanoid robots: Stepping over large obstacles dynamically. In *International Conference on Mechatronics and Automation, ICMA, LuoYang - Henan, China, June 25-28*, pages 1072–1079, June 2006.