In humanoid robots, as in humans, bipedal standing should come before bipedal walking

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1 Introduction

In humans the ability to stand up on two legs is a necessary prerequisite for bipedal walking. Moreover, there is ample neurophysiological evidence that standing and walking are rather independent control mechanisms. Therefore, we suggest that also humanoid robots should be trained first to master the unstable standing posture and then learn to walk.

Moreover, the postural control system must face three problems: P1) stabilize the inverted pendulum that characterizes the bipedal standing posture; P2) compensate the postural perturbations induced by movements of the upper part of the body; P3) coordinate the redundant set of degrees of freedom of the lower and upper part of the body in whole body gestures, like whole body reaching (WBR).

The easiest way to solve P1 would be to use a "stiffness strategy", in particular at the ankle joint which of course is the most critical one. However, this is not what humans do, because the ankle stiffness is dominated by the elasticity of the Achilles tendon and this is consistently smaller than the toppling torque due to gravity [1]. There is a functional merit to this solution because a rather compliant ankle joint avoids high impact forces with the ground and more easily adapts to uneven ground; on the other hand, there is a computational price to be paid because with a compliant ankle the stability of the standing posture is an active process, not the indirect consequence of the material properties of the ankle & ankle actuators.

As regards the nature of the active stabilization process, two alternatives have been considered: 1) continuous time PD feedback mechanism [2]; 2) intermittent, switching control strategy [3]. It has been demonstrated [4] that the latter mechanism is more robust and better captures the spectral properties of human sway.

In principle, P2 can be solved by the same intermittent control mechanism of P1, provided that the self-generated postural disturbances are not too great. Again, the robustness of the intermittent stabilization mechanism is crucial from this point of view.

P3 implies a different issue, in particular if the target of the focal movement is beyond arm's length: postural stabilization basically involves a single degrees of freedom, whereas WBR recruits all the degrees of freedom of the global kinematic chain, with a high degree of redundancy. It has been shown [5] that the joint rotations patterns of WBR movements can be reproduced with good accuracy by a computational model based on a force-field approach, named Passive Motion Paradigm (PMP [6]). The basic idea is the observation that motor commands for any kind of motor action, for any configuration of limbs and for any degree of redundancy can be obtained by an "internal simulation" of a "passive motion" induced by a "virtual force field" applied to a small number of task-relevant parts of the body. Here "internal simulation" identifies the relaxation to equilibrium of an internal model of limb (arm, leg etc, according to the specific task); "passive motion" means that the joint rotation patterns are not specifically computed in order to accomplish a goal but are the indirect consequence of the interaction between the internal model of the limb and the force field generated by the target, i.e. the intended/attended goal. The model is based on non-linear attractor dynamics where the attractor landscape is obtained by combining multiple force fields in different reference systems. We already used this approach for the coordination of bimanual movements of the humanoid robot iCub [7]. Here we propose to use the same computational framework for WBR tasks with the bipedal standing iCub. We tested the feasibility of this computational mechanism using the iCub simulator, not the real robot, because at the moment the robot cotroller cannot support bipedal standing.

2 WBR with iCub

The PMP network for the coordination of focal and balancing movements is shown in fig. 1. The basic sub-network that implements the focal part corresponds to the grey-shaded blocks. The sub-network that implements the balancing part corresponds to the vertically-striped blocks. The square-patterned block introduces terminal attractor dynamics ($\Gamma(t)$ is the time base generator). The sub-network with horizontally-striped blocks generates a smoothly moving target $x_T(t)$ from the initial position of the hand to the designated target x_F. J_F is the Jacobian matrix of the overall kinematic chain (from feet to hands) used for the focal part of the task and K_F is the corresponding stiffness matrix in the extrinsic space; J_P is the Jacobian matrix of the subset of the kinematic chain, up to the hip, that is used for the postural part of the task; A is the admittance matrix in the intrinsic space; B is the viscosity matrix, in the intrinsic space, which aims at reducing the forward shift of the COM (Center of Mass). F_F is the force-field, in the extrinsic space, related to the focal part of the task; F_P is the force-field, in the intrinsic space, related to the postural part of the task. K_F, A, B remain constant during a movement; J_F, J_P are functions of q and thus change during a movement.

The network of fig. 1 is a kind of “internal model” that implements the WBR synergy. By running it the iCub brain generates joint rotation patterns that allow the end-effector to reach the target and, at the same time, reduce the range of motion of the COM on the support base.

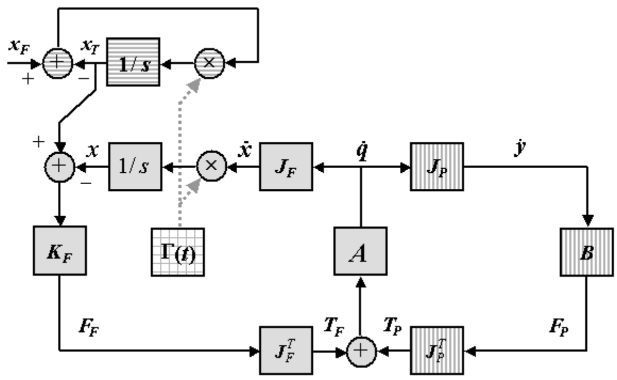

Fig. 1. PMP network for WBR.

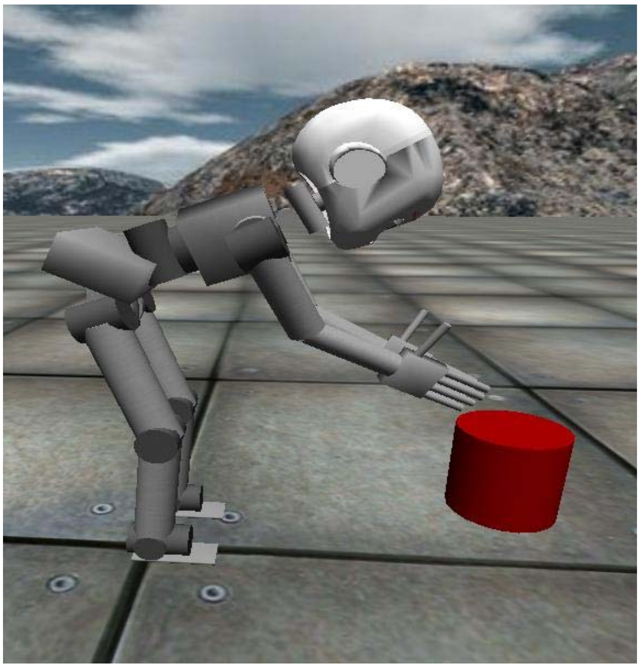

Figure 2a and b. Simulations of the WBR model for different values of the admittance matrix.

3 Future developments

In the near future we plan to test the proposed synergy formation mechanism on the real iCub. In the first experiments we shall rely of the stiff PID controllers of the joints which are currently operational. The following step should be to increase the compliance of some joint, such as the ankle, thus integrating the intermittent postural controller of some crucial joint (like the ankle) with the WBR synergy formation mechanism. At that point, iCub will be ready for the first step forward.

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