A comparison between control strategies for balancing with an actuated ankle orthosis: preliminary simulation results

Amber Emmens, Gijs van Oort, Edwin van Asseldonk and Herman van der Kooij
University of Twente, Enschede, the Netherlands
a.r.emmens@utwente.nl

1 Introduction

By wearing an exoskeleton, people with spinal cord injury can regain or improve their ability to walk. However, it can be difficult for paraplegics to balance in such devices without additional supporting aids. A solution for this problem can be to design more sophisticated controllers for the exoskeletons, that specifically focus on balance control. As a first step we will develop a controller for an exoskeleton for paraplegics with a low lesion, who have sufficient hip control: the actuated ankle-foot orthosis "Achilles" [1].

In this study we compare momentum-based balance control strategies with a PD-controller in center of mass (CoM) space, in order to find the best strategy for standing balance in the sagittal plane with Achilles, based on perturbation handling and robustness to human variation.

2 Methods

For the simulations, a human model is created in the sagittal plane with two joints (hip and ankle) and a HAT (head-arms-trunk), leg and foot segment. Because the Achilles can only deliver torques around the ankle, for the hip a human controller is modelled using experimentally identified intrinsic stiffness, reflexive feedback and neural time delays [2], with the addition of intrinsic damping. For the ankle joint the Achilles controller is modelled with limit torques of $\pm$ 100 N. This shared control strategy is shown schematically in figure 1. For the ankle joint 3 different model-based controllers will be compared:

- CoM-C: PD-Controller on the CoM that tries to place the CoM above the ankle.
- MB-C: Momentum-based Balance Controller that tries to find joint torques such that a certain desired momentum is obtained [3] [4]. By optimization, torques are found that satisfy constraints on the center of pressure (CoP), joint angle limits and limit torques. Both ankle and hip torques are obtained that together have the desired effect, but as the hip has a human controller, the latter are discarded. Therefore the combination of implemented ankle and hip torque may not be optimal.
- cMB-C: similar to MB-C, but now the angular acceleration of the trunk is computed and used as a constraint in the optimization procedure. Therefore the obtained ankle torque will have an optimal effect, given the hip torque produced with the human controller.

In order to find which strategy is the best, for each controller we want to find the maximum perturbation that can be applied, without making the model fall and while keeping the CoP inside the base of support. This is done by applying a 'push' force on the trunk during 0.1 s at the beginning of each simulation. If the controller is able to balance the model, the perturbation force will be increased stepwise with 10 N, until the system cannot be stabilized any more. The ankle controller settings were chosen such that the maximum perturbation was tolerated while applying the least amount of ankle torque. To check if the controllers are robust to human variation, we change the standard values of the reflexive hip stiffness in the human controller slightly and compare the results. Outputs of the simulation are the maximum perturbation force and, for each trial, the CoM and CoP on the anteroposterior (AP) axis and the joint angles.

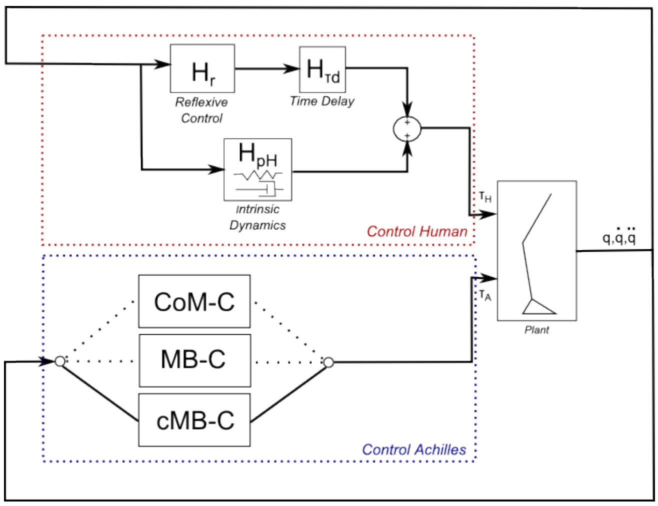

Figure 1: Shared control by the human and the Achilles. From the joint angles q of both hip and ankle, the hip torque τ_H is generated by the human and the ankle torque τ_A by the Achilles. For the orthosis 3 different controllers are compared.

3 Results and Discussion

Due to the perturbation the CoM of the model moves away from its desired location. Figure 2 shows that all three controllers move the CoM back above the ankle and are able to balance the model while keeping the CoP inside the base of support. The found maximum admissible perturbation force of 340 N is the same for all three controllers, when the step size of the force increment is 10 N. The restricting factor on this maximum perturbation force is the torque limit of the Achilles controller. As the ankle torque and the CoP are related, this also induces a limit on the location of the CoP, that is well within the base of support (see figure 2).

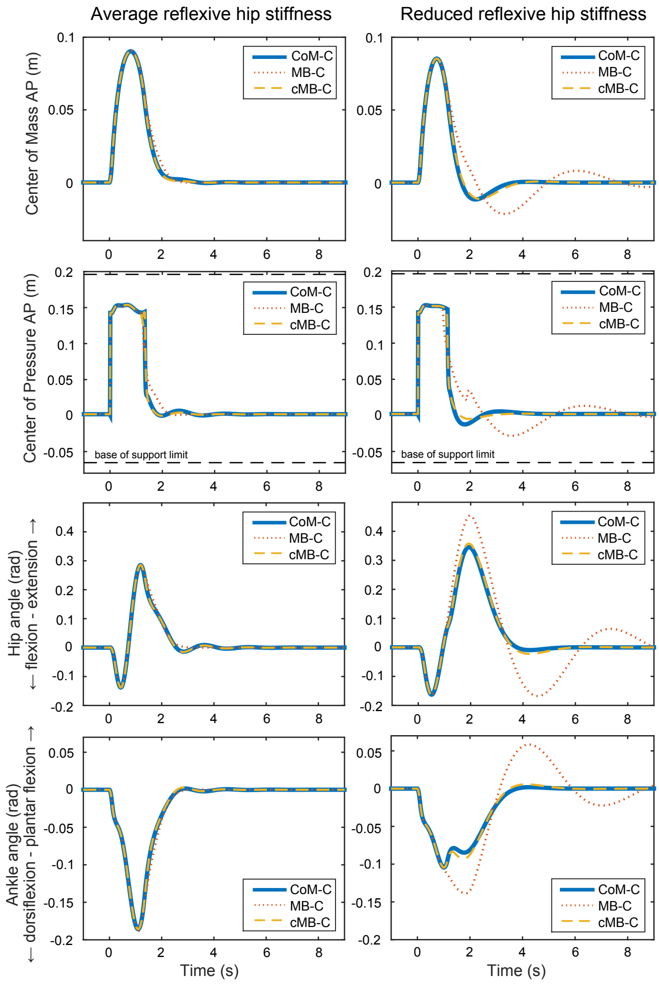

Figure 2: CoM, CoP, hip angle and ankle angle for the standard value of the reflexive hip stiffness (left column) and reduced reflexive hip stiffness (right column). The applied (maximum) perturbation force is 340 N.

Figure 2 also shows that the joint trajectories obtained with the cMB-C and CoM-C are almost identical. A difference between the two controllers is that in the momentum-based balance control strategy not only the linear momentum of the CoM is controlled, but also the angular momentum. However, the latter is mainly generated by the hip, so with the ankle controller little angular momentum can be produced. Therefore the results obtained with both controllers are similar.

In case of standard reflexive hip stiffness, the MB-C also shows smooth joint trajectories similar to the other controllers, but when this stiffness is reduced, large oscillations are obtained (see figure 2). Because the MB-C shows less robustness to human variation, this strategy is least suitable for human standing balance.

These simulation results form the basis for balancing experiments that we will do in the near future with paraplegics and the Achilles orthosis.

Acknowledgement

The work presented here was performed in the SYMBITRON project which is supported by EU research program FP7, FET-Proactive initiative "Symbiotic human-machine interaction" (ICT-2013-10) under project contract #611626. The SYMBITRON project is coordinated by University of Twente.

References

[1] C. Meijneke, W. van Dijk, H. van der Kooij, "Achilles: An Autonomous Lightweight Ankle Exoskeleton to Provide Push-Off Power," IEEE, 2014.

[2] D. Engelhart, J.H. Pasma, A.C. Schouten, R.G.K.M. Aarts, C.G.M. Meskers, A.B. Maier, H. van der Kooij, "Adaptation of multi-joint coordination during standing balance in healthy young and healthy old individuals," Unpublished Manuscript, 2015.

[3] A. Herzog, L. Righetti, F. Grimminger, P. Pastor, S. Schaal, "Momentum-based Balance Control for Torque-controlled Humanoids," http://arxiv.org/abs/1305.2042v1, 2013.

[4] S.H. Lee, A. Goswami, "A momentum-based balance controller for humanoid robots on non-level and non-stationary ground," Springer US, 2012.