Walking velocity transitions in a simple powered walker

Lowie H. F. van Zijl, Steven H. Collins
Delft University of Technology,
Delft Biorobotics Lab; email: L.H.F.vanZijl@student.tudelft.nl, web: www.dbl.tudelft.nl

SUMMARY

Dynamic walkers are capable of walking with low energy use and high robustness, however they have not demonstrated great versatility. For instance none to date have been able to quickly make a large velocity change. We showed that a significant walking speed transition can be made within one transition step. We applied dynamic walking methods to the transition step, in an attempt to make use of the advantages of low energy use and simple control. We also investigated optimization of energy use and robustness for such transitions. We realized a velocity increase of 6 times the initial walking speed within one step in the powered simplest walking model. The transition step strategy could be applied to more extended models or robots and to transitions between other legged locomotion actions, and may lend insight into human coordination strategies.

MODEL AND APPROACH

We used an extended version of the powered simplest walking model [1], a double pendulum model with a point mass in the hip and massless feet. Energy is added into the system by push-off impulse P directed to the hip mass and the massless swing leg is actuated by a combination of hip stiffness K_P and a torque τ. Each fixed point has a corresponding set of control inputs P, K_P and τ.

We approached a walking speed transition as one dynamic walking step with different control input values, starting with the initial conditions of the first walking cycle (fixed point x_1^*) and ending with the initial conditions for the second walking cycle (fixed point x_2^*). The response to disturbances was investigated by applying a step-down disturbance and a Gait Sensitivity Norm [2].

TRANSITION STEP REALIZATION

We used the gradient search method to obtain the needed control input values for P, K_P and τ to realize a transition between two fixed points, minimizing the Euclidean distance between the end of the transition step and fixed point x_2^*. In spite of the fact that the system consists of only two independent generalized coordinates on the Poincaré section, we used three control inputs to bring about the walking speed transitions. This implies that the system is underconstrained, which leaves room for optimization of energy use and robustness.

ROBUSTNESS AND TARGETING

Cyclic stability, which is important in dynamic walking, does not hold for the transition step, because it is only one step that ends in a different state than it started. Still, the transition has to be robust against disturbances, which can occur before and during the transition step.

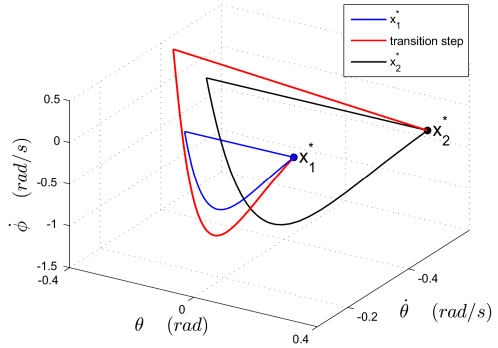

Figure 1, Phase space representation of one step through x_1^* (with speed v=0.2) followed by the transition step and one step through x_2^* (with speed v=0.4).

We describe the ability of a walker to avoid falling in spite of the presence of a disturbance as its robustness. However, many simulation steps are needed to calculate whether the walker will fall or not. A fall is a direct consequence of the fact that the transition step did not end exactly at x_2^*. This means that robustness might be improved by making the transition step end closer to x_2^*. We will refer to the ability to end the transition step in or close to x_2^* in spite of disturbances as “targeting”. The targeting performance might be improved by applying state feedback control, by adjusting the control inputs for the transition in proportion to the deviation from x_1^*.

RESULTS AND DISCUSSION

We showed in simulation that it was possible to realize a one-step transition ending with a gait with 6 times larger dimensionless velocity than before the transition. A velocity-decreasing transition was possible as well, but with a maximal decrease of only 20% of the initial velocity because energy could only be dissipated during foot strike in this model.

Using state feedback control on the transition step with available control inputs P, K_P and τ, the robustness was improved. A step-down disturbance prior to the transition resulted in perturbed initial conditions at the start of the transition. Without state feedback control only a step-down of 0.1% of the leg length could be overcome. With state feedback control the system was able to handle a step-down of 2% leg length.

REFERENCES

1. Kuo, AD. *J. Biomech.* **124**, 113-120, 2002
2. Hobbelen, D.G.E. and Wisse, M. *IEEE J. Robotics*, **23**, 1213-1224, 2007