Deriving biped controllers from human experiments

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Humans are agile, stable and energy efficient walkers. We use human dynamics as a basis to design biped controllers which may potentially exhibit the same features. To do this, we first investigate human walking behaviour through perturbation experiments. We collected kinematic and kinetic data from 12 subjects as they walked on an instrumented split-belt treadmill. These subjects were perturbed by applying randomly timed discrete pulls through an inelastic cord attached at their hips. From this human data, we determine a linear foot-placement controller –

$$\Delta \begin{bmatrix} X_{\text{foot}} \\ Y_{\text{foot}} \end{bmatrix} = \begin{bmatrix} 1.85 & 1.99 & 0.22 \\ -0.49 & -1.65 & 0.85 \end{bmatrix} . \Delta \begin{bmatrix} X_{torso} \\ \dot{X}_{\text{torso}} \\ \dot{Y}_{\text{torso}} \end{bmatrix}$$

This controller tells us to increase step width in response to forward pushes and rightward pushes, and to increase step length in response to forward pushes and leftward pushes when the left leg is in stance.

For a given biped model, such as the commonly used inverted pendulum model shown in fig 1,

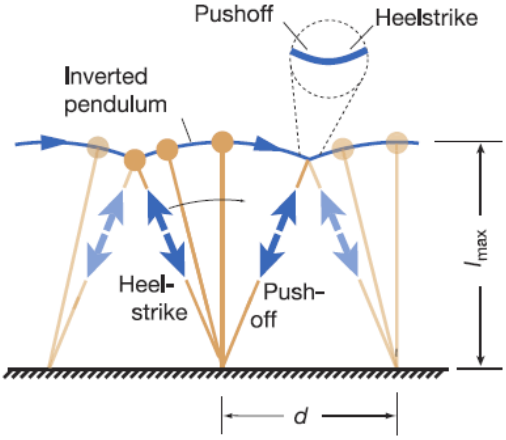

Figure 1: Inverted Pendulum model of biped locomotion. Each step is an inverted pendulum with a push-off and a heel-strike impulse at the end of stance. The swing leg is not modelled.

using this foot placement controller, we determine a push-off impulse controller which makes the state-transition matrix of the model approximate that of the human. We find -

$$\Delta \left[I_{\text{pushoff}} \right] = \left[-0.18 \quad -0.69 \quad -0.52 \right] . \Delta \begin{bmatrix} X_{\text{torso}} \\ \dot{X}_{\text{torso}} \\ \dot{Y}_{\text{torso}} \end{bmatrix}$$

which tells us that we mush decrease push-off impulse in response to both forward and rightward perturbations when the left leg is in stance. To our knowledge, this is the first complete biped controller (with foot-placement and push-off control) derived entirely from human data. We can similarly derive controllers for biped models of varying complexity. Such controllers might inform the design of robots and prosthetics.

References

Y. Wang and Manoj Srinivasan, “Stepping in the direction of the fall: Torso-state dependent foot placement strategies for stabilizing human walking inferred from steady-state walking data”, Biol. Lett., vol. 10, sep 2014