One step is enough: Prediction of human walking adjustments on complex terrain

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***Abstract*—Humans actively adjust their speed in anticipation of upcoming terrain [1]. A complex terrain profile could potentially call for a complex anticipatory adjustment. But optimization of a biped model suggests that the speed dynamics are fairly linear and superimposable. The speed fluctuation waveform for a complex series of steps should be decomposable into that for a single uneven step (“1-step”), which in turn should predict that for other complex (“N-step”) profiles. We tested this by measuring humans (N = 11) walking over complex terrain, and comparing with a minimum-work model prediction. We deconvolved the N-step waveforms into corresponding 1-step waveforms for humans and model, and found them to be similar to each other. They also both predicted the waveform for an independent N-step profile. Near-optimal control for complex terrain may be achieved through scaling and superposition of a relatively simple, anticipatory adjustment for a single uneven step.**

I. Introduction

It is challenging to compute a control plan for an animal or robot to negotiate complex terrain, yet humans walk on a variety of surfaces with little conscious thought. Perhaps there is a simple solution to the apparently complexity of anticipatory planning for uneven terrain. A dynamic walking model based on the rimless wheel offers simplicity in step-to-step dynamics, where speed fluctuations, or equivalently, push-off commands are fairly superimposable. Superposition suggests that movement planning over complex terrain could be a matter of repeatedly applying the optimal speed waveform for a 1-step disturbance, one step at a time, rather than requiring global planning for all steps at once.

There are two implications to superposition. The first is that the optimal waveform for an N-step terrain profile can be deconvolved into the optimal waveform, or kernel, for a 1-step disturbance, which can be predicted by model. The kernel describes speed fluctuations in the steps before and after a single small perturbation. Second, the 1-step kernel may also be convolved with an arbitrary ground profile to compose new speed fluctuations. We therefore tested the generalizability of the 1-step kernel using both deconvolution and convolution.

II. Methods

We predicted model speed fluctuations and measured human speed fluctuations [2] (N = 11) on a 17 steps uneven terrain profile (Figure 1, top row). We deconvolved these waveforms with the profiles, yielding hypothetical 1-step kernels (Figure 1, bottom row) for a single upward step perturbation. We tested whether the kernels included anticipatory speed adjustment before the perturbation, as well as whether they could compose speed fluctuations for an independent terrain profile for both model and human (Figure 1, top row).

III. Results

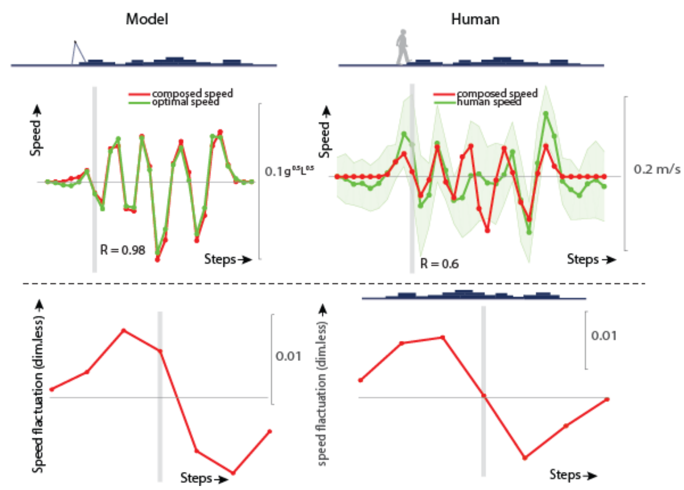

Figure 1: Model (left) and human (right) compensations on uneven terrain. Independent uneven terrain (top row) for testing, with resulting speed fluctuation waveforms, measured and composed speeds (shaded area for human ±1 st. dev.). Deconvolved 1-step kernels of the model and the human (bottom row; vertical bar denotes the uneven step). The 17 steps profile that the human 1-step kernel is found from is also shown (bottom row, right)

The identified 1-step kernel for human agreed well with the optimal 1-step kernel of the model (R = 0.81) for minimum work. Both showed a strategy of speeding up before the perturbation, then slowing down on that step, and finally speeding up again (bottom row). The kernels also predicted well the speed waveforms for an independent 17 steps uneven terrain (top row, $R_{model} = 0.98$, $R_{human} = 0.6$).

IV. Concluisons

The same strategy for compensating for a single terrain perturbation also applies to many in succession. The strategy is anticipatory and is also compatible with optimizing for minimum work and suggests a simple and near-optimal way to plan for arbitrary ground profiles, through linear superposition.

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References

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