Gait planning and control of walking robots based on energy regulation between steps

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***Abstract*—We show how a simple control scheme that manages energy between key points in the gait cycle using foot placement and ankle push-off can be used to generate walking motions over a wide combinations of walking speeds and step lengths (gait planning) and can be made robust to external disturbances (control).**

I. Introduction

Our quest is to develop to develop energy-efficient, versatile and robust bipedal robot locomotion using simple models and simple control schemes. We present some progress in this direction.

II. Methods

Our model is similar to the model used by Kuo [3] and Srinivasan and Ruina [4]. The model consists of mass-less legs and a point mass at the hip. A hip actuator can place the leg instantaneously fast at the desired location. A linear actuator on the legs can generate an impulsive push-off along the leg.

A typical step of the model and is shown in Fig. 1. The walker starts in the upright or mid-stance position in (I). Next, just before heel-strike in (II), the stance leg applies an impulsive push-off P_i and the hip actuator positions the swing leg at an angle $2\theta_i$. Next, after heel-strike in (III), the swing leg becomes the new stance leg. Finally, the walker ends up in the upright position or mid-stance position on the next step in (IV). Note that model moves passively from (I) to (II) and from (III) to (IV) (the cost of moving the mass-less swing leg is zero). The push-off impulse at (II) and the heel-strike impulse at (III) (heel-strike impulse is not shown) serves to re-direct the point mass from one circular arc to the next one. Note that the angular velocity is always perpendicular to the stance leg at all instances of time.

The mid-stance velocity at step $i+1$ ($\dot{\theta}^m_{i+1}$) can be expressed as a function of the mid-stance velocity at step i ($\dot{\theta}^m_i$) and the two controls P_i and θ_i,

$$\dot{\theta}^m_{i+1} = f(\dot{\theta}^m_i, \theta_i, P_i) \quad (1)$$

The key idea behind gait planning and control is to *measure* the mid-stance velocity at the current step, $\dot{\theta}^m_i$, and use a combination of the two *controls*, namely foot placement θ_i and push-off impulse P_i to *regulate* the mid-stance velocity at the next step, $\dot{\theta}^m_{i+1}$ (see Eqn. 1).

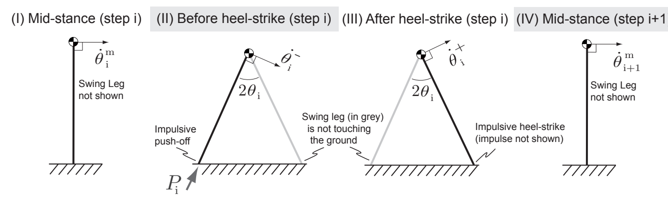

Fig. 1. **A typical step of our point mass model.**

III. Results

We show that by regulating the robot kinetic energy between steps using Eqn. 1, we are able to: 1) generate a wide range of walking speeds and stride lengths, including average human walking; 2) cancel the effect of external disturbance fully in a single step (dead-beat control); and, 3) switch from one periodic gait to another in a single step. More details are in reference [2].

We have also used a similar control scheme to control our legged robot, Cornell Ranger, leading to a 40 mile non-stop walking record [1].

References

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