Novel leg adjustment approach for hopping and running

Maziar A. Sharbafi[1,2], Andre Seyfarth[1], Majid Nili Ahmadabadi[2] and Mohammad J. Yazdanpanah[2]
[1]Lauflabor Locomotion Laboratory, TU Darmstadt, Germany, [2]CIPCE, University of Tehran, Iran.
sharbafi@sport.tu-darmstadt.de

1 Motivation

The ability to perform efficient and robust locomotion is crucial condition for real-world legged robots. Unlike running and walking [1], stable hopping cannot be achieved with a fixed angle of attack with respect to ground. Also, the region of attraction for stable running is quite small with fixed angle of attack. This drawback and sensitivity to running velocity and control parameters exist in common leg adjustment methods. In this study, the superiority of the new method regarding aforementioned concerns is shown for running and hopping SLIP model. Its similarity to human hopping strategy to cope with perturbation was shown in [2]. The presented method, called VBLA (Velocity Based Leg Adjustment) can achieve dead beat response for perturbed hopping. With this approach, running in a large range of velocities can be obtained.

2 State of the Art and our Approach

Leg adjustment strategies following the Raibert approach [3] rely on the Center of Mass (CoM) horizontal speed v_x and its desired value v_x^d

$$x_f = k' v_x T_s/2 + k(v_x - v_x^d) \tag{1}$$

Where, k and k' are control constants and x_f, is the horizontal distance between the desired foot point at touch down and hip point. Since for SLIP model the equations are not integrable during stance phase, T_s is an estimation of the stance time, obtained by solving it just for vertical direction, tuned k'. This results in a fixed period for different horizontal velocities corresponding to a fixed vertical speed.

Recently, various strategies were investigated by Peuker et al. [4] stating that leg placement w.r.t the CoM velocity vector $\vec{V}$ and the gravity vector $\vec{G}$ yielded the most robust and stable hopping and running motions. Defining the angles of $\vec{G}$ with $\vec{V}$ and leg orientation by γ and α, this method gives the leg orientation by $\alpha = \mu\gamma$, where $0 < \mu \leq 1$. We present VBLA as a modified version of this strategy: the leg direction is given by vector $\vec{O}$, a weighted average of $\vec{V}$ and $\vec{G}$,

$$\vec{O} = \mu\vec{V} + (1-\mu)\vec{G} \tag{2}$$

3 Current Results

It can be shown that with $\mu = 1/(1-\pi\sqrt{M/k_s})$ the dead beat response is achievable via VBLA for perturbed hopping. In which, the spring stiffness k_s and mass M should satisfy $k_s > \pi^2 M \approx 10M$, held in reasonably large range of stiffnesses for each mass. Thus, with this approach it is possible to attenuate all perturbations at most in two steps.

The methods are compared w.r.t their abilities in making stable running for fixed sets of parameters. Fig. 1 shows running stability for different control parameters and speeds. In

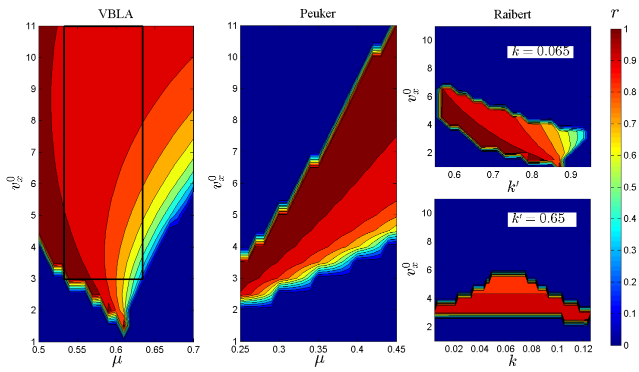

Figure 1: Performance and stability of different methods. The colors show the ratio of final to initial horizontal velocity $r = \frac{v_x^*}{v_x^0}$. The dark blue area ($r = 0$) shows the instability.

VBLA, the sensitivity to control parameter is smaller when all speeds above 3 m/s are achievable with $0.53 \leq \mu \leq 0.64$ (shown by the rectangle in Fig. 1 left) and the stable range is larger than two other methods. It also keeps the initial velocity (v_x^0) in a considerable area of $\{v_x^0,\ \mu\}$, when r is near one. In addition, with $\mu = 0.61$, running from 1.5 m/s to 11 m/s is possible with the proposed approach.

4 Best Possible Outcomes

The VBLA shows the best performance of leg adjustment for perturbed hopping and running in simulation of SLIP model. As an important task in locomotion, it can be merged with other control techniques for stance phase like balancing and leg length adjustment for more complex models of running and walking (See [5] for perturbed hopping with trunk).

References

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