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Push recovery for the standing under-actuated bipedal robot using the hip strategy

Key words: Push recovery, Balance control, Bipedal robot, Hip strategy

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Introduction

- To avoid falling and achieve better walking performance, a class of controllers must be developed to maintain balance and recover upright posture for bipedal robots.

- The algorithms proposed attempt to achieve both CoM position control and upper body attitude control during push recovery for bipedal robots during standing using only the hip strategy.

- Compared with closed-loop control, the open-loop methods in this paper of torque primitives serve more like a reflex control, being fast and rapid.

Three different types of external force/torque disturbances

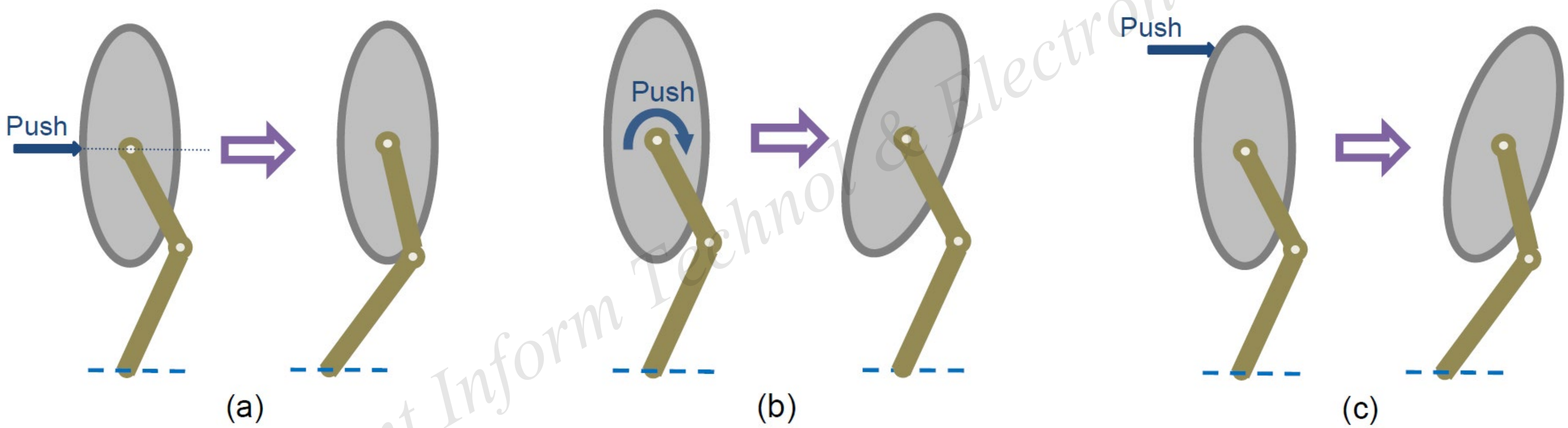

Fig. 2 Three different types of external force/torque disturbances
(a) External force passes through the CoM; (b) External torque is applied on the CoM; (c) External force misaligns with the CoM

External force passing through the CoM

- The STB torque primitive

$$\tau_{\mathrm{STB}}(t) = \mathrm{sgn}(S_0)\cdot\tau_{\max}\left[1(t) - 2\cdot 1\left(t-\frac{T}{4}\right) + 2\cdot 1\left(t-\frac{3T}{4}\right) - 1(t-T)\right], \quad (14)$$

- The trajectories of horizontal motion in the phase portrait using STB control

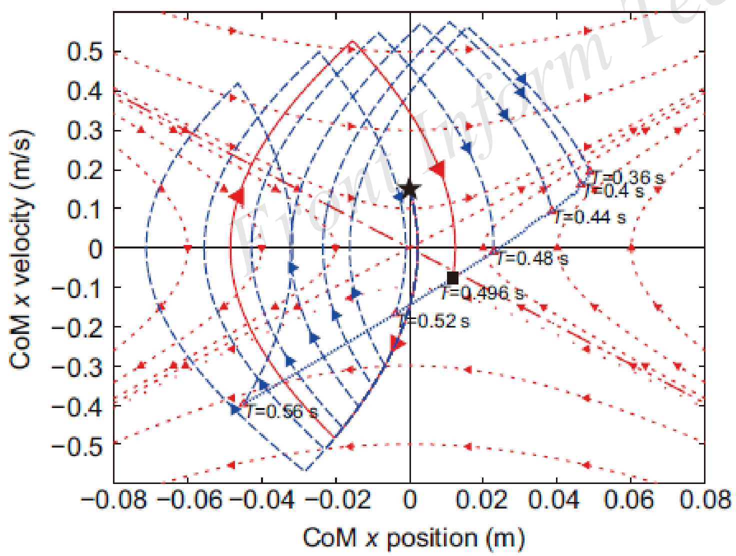

Fig. 3 Trajectories (blue dot curves) of the horizontal motion in the phase portrait with stable orbit (red dot curve) using STB control with different T (0.36–0.56 s) from the initial state of x_0=0 m, $\dot{x}_0 = -0.15$ m / s (pentagram)

External torque applied to the CoM

- The ATB torque primitive

$$\tau_{\text{ATB}}(t) = \text{sgn}(\theta_0) \cdot \tau_{\max} \left[1(t) - 2 \cdot 1(t - aT) + 2 \cdot 1(t - bT) - 1(t - T) \right], \quad 0 \le a \le b \le 1, \tag{18}$$

- The trajectories of horizontal motion in the phase portrait using ATB control

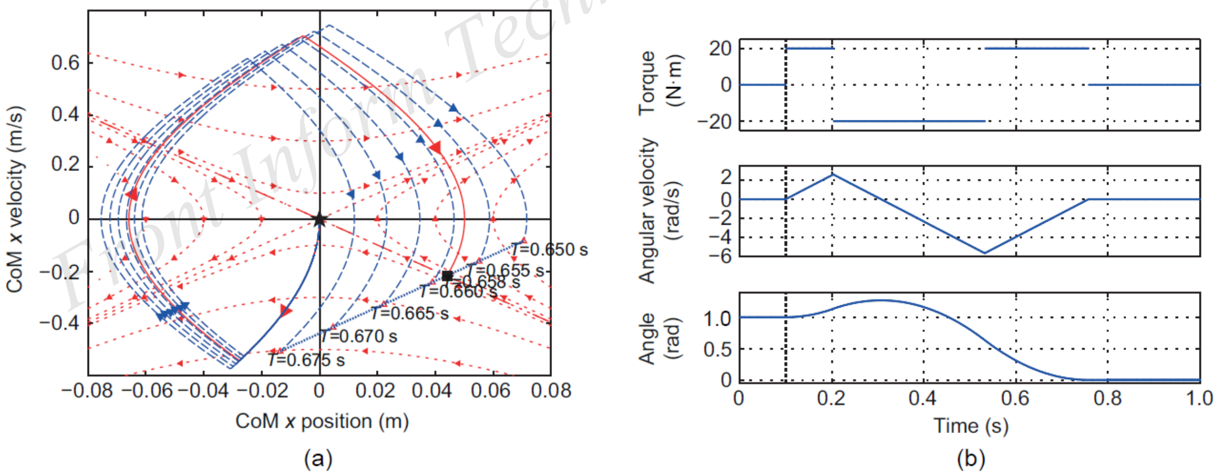

Fig. 5 Trajectories (blue dot curves) of the horizontal motion in the phase portrait with stable orbit (red dot curve) using ATB control with different duration T (0.650–0.675 s) from the initial state of x_0=0 m, $\dot{x}_0$ =0 m/s and posture of θ_0=0 rad, $\dot{\theta}_0$ =1 rad/s (a) and the curves of the ATB torque primitive for the hip with T =0.658 s (top), the angular velocity (middle), and angle (bottom) of the body (b)

External force misaligning with the CoM

- The UTB torque primitive

$$\tau_{\text{UTB}}(t) = \text{sgn} \cdot \tau_{\max} \left[1(t) - 2 \cdot 1(t - aT) + 2 \cdot 1(t - bT) - 1(t - T) \right], \quad 0 \le a \le b \le 1, \tag{32}$$

- the trajectories of horizontal motion in the phase portrait using UTB control

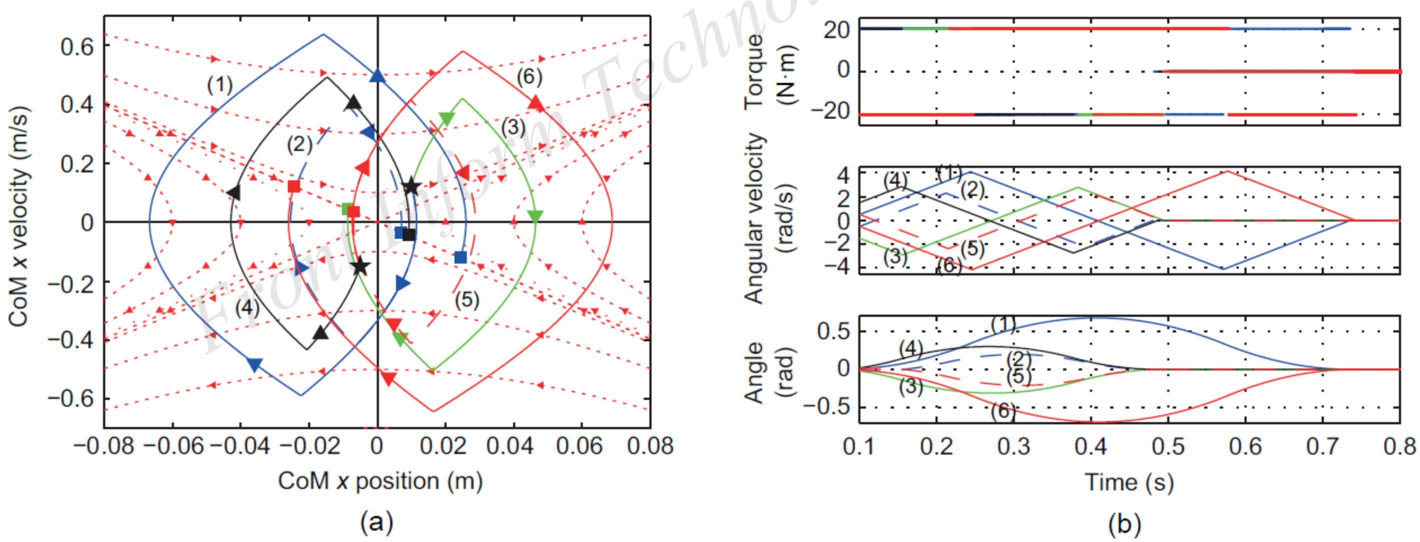

Fig. 6 Six trajectories of the horizontal motion in balance control using UTB control from six different initial horizontal motion states (pentagrams) to their final states (rectangles) respectively in the phase portrait (a) and the six corresponding data of the UTB torque primitive for the hip (top), angular velocity (middle), and angle (bottom) of the body (b)

Simulation results

- STB control

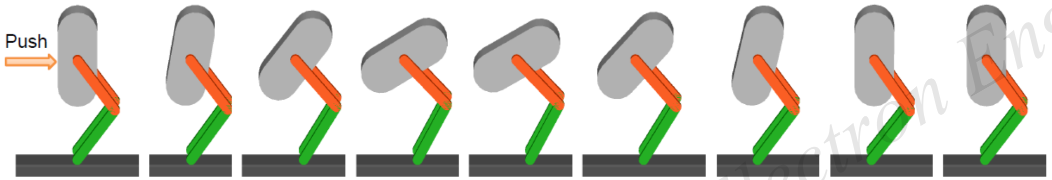

Fig. 7 Time-elapsed snapshots from dynamic simulation where the simulated biped recovers from an impulsive disturbance using STB control (snapshots are sequenced from left to right at a 0.08 s interval)

- ATB control

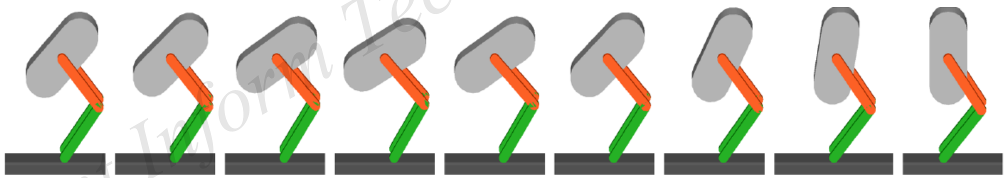

Fig. 9 Time-elapsed snapshots which show that the simulated biped recovers posture from 0.75 to 0 rad using ATB control (snapshots are sequenced from left to right at a 0.05 s interval)

- UTB control

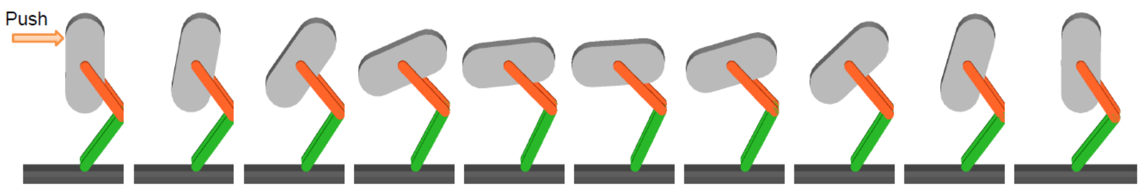

Fig. 11 Time-elapsed snapshots showing that the simulated robot recovers from an impulsive disturbance by UTB control (snapshots are sequenced from left to right at a 0.08 s interval)

Conclusions

- Three different hip strategies were proposed for simultaneously controlling the standing balance and body posture under different impulsive force disturbances on bipedal robots.

- More types of torque primitives have been tested to complete both balance control and posture recovery. However, the bang-bang-bang control is the fastest.