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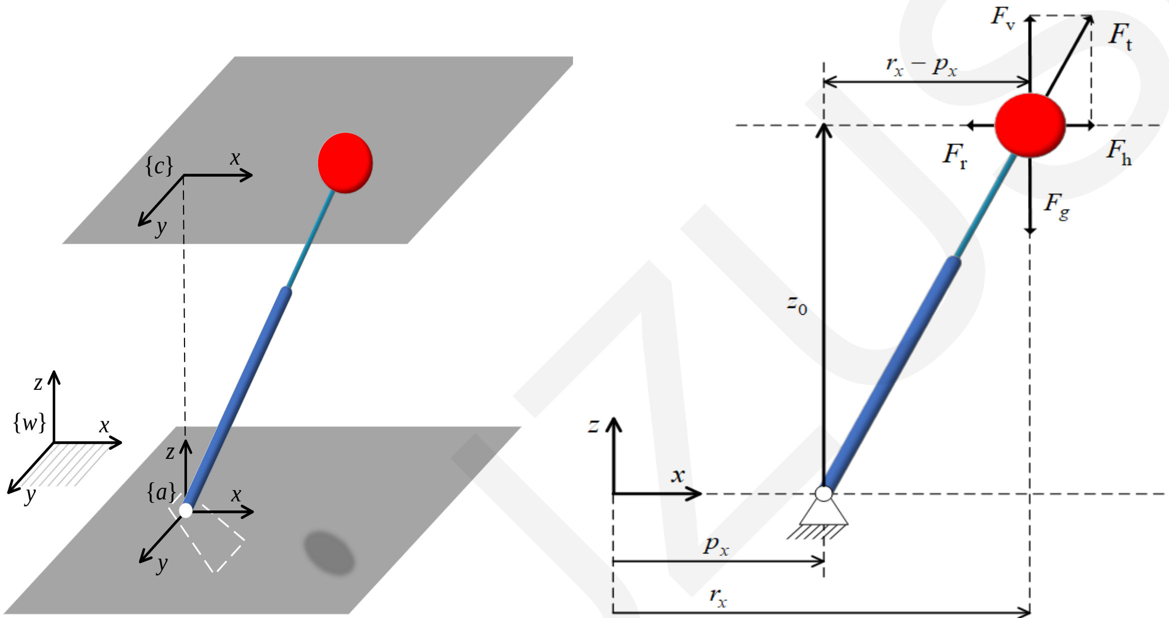
COM trajectory planning and disturbance-resistant control of a bipedal robot based on CP-ZMP-COM dynamics

Key words:

Bipedal robot, CP-ZMP-COM dynamics, COM trajectory planning, feedback compensation control

CP-ZMP-COM Dynamics

Kajita et al ensured the simplicity and flexibility of classical gait-planning methods, borrowing the idea of "preview controllers" that optimize current decisions based on future information to optimize the inevitable foot-placement. We propose a closed-loop feedback-control method for bipedal robot COM trajectory planning and resistance to external force disturbances based on CP-ZMP-COM dynamics.



(a) Three-dimensional model (b) Decoupled model in the *x*-*z* plane

Fig. 1 LIPM for bipedal robot.

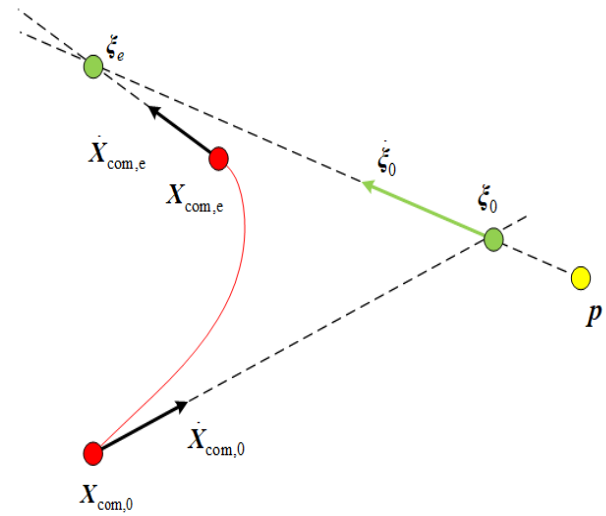


Fig. 2 Kinematic relationship among ZMP, CP, and COM. The path of COM is represented by the red curve.

Anti-disturbance feedback compensation control

During walking, adults exhibit a swaying motion of their COMs in the sagittal plane, resembling that of an inverted pendulum, as they dynamically adjust their step lengths. Therefore, coordinating the foot placement of the robot in both the sagittal and coronal planes was crucial to counteracting external disturbances.

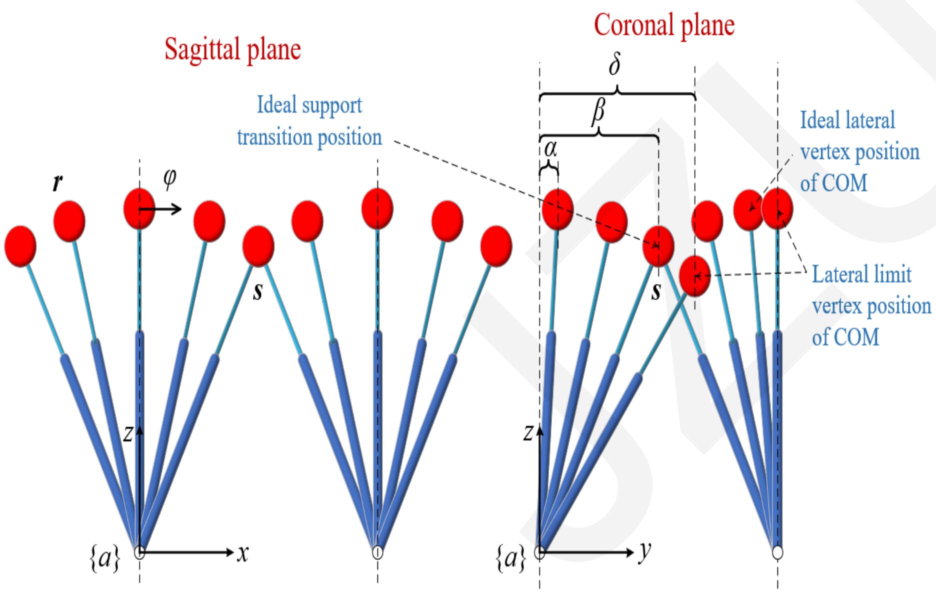


Fig. 3 Gait parameters in sagittal and coronal planes of bipedal robot during walking process.

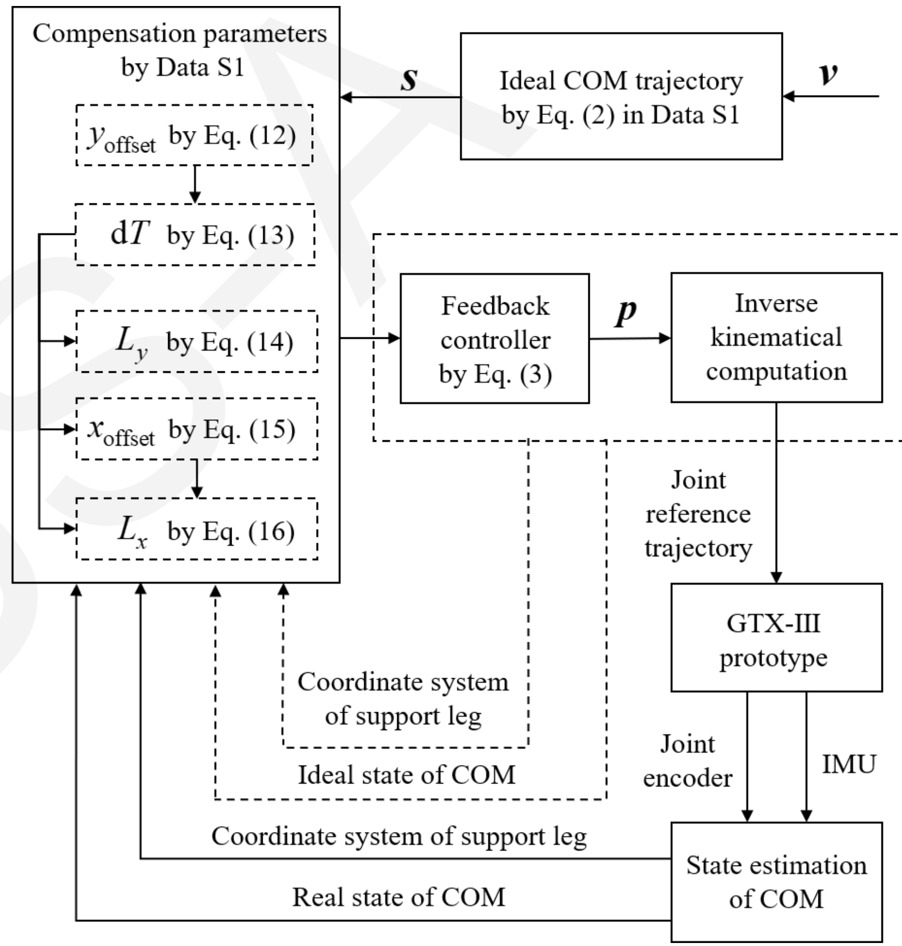
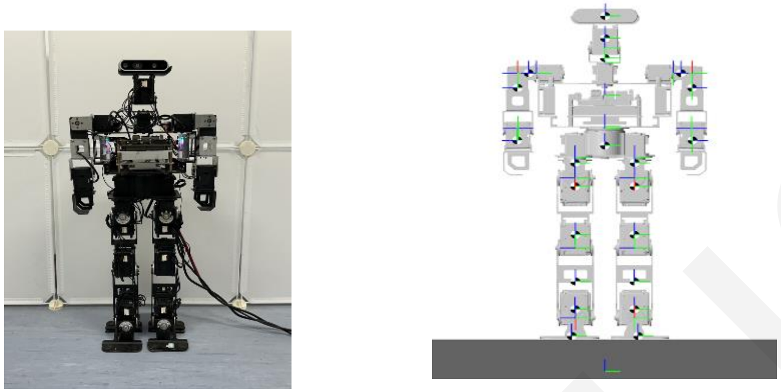


Fig. 4 Algorithm flowchart for the feedback compensation control method.

Simulation and Experimental Validation

■ Lateral walking experiments based on the COM trajectory-planning method



(a) Physical prototype (b) Simulink simulation model

Fig. 5 Miniature bipedal robot GTX-III.

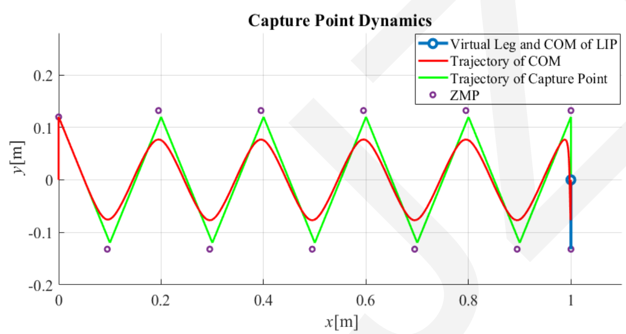


Fig. 6 Lateral walking simulation results based on the COM trajectory-planning method, with a lateral step width of 0.1 m and ideal walking cycle of 0.8 s.

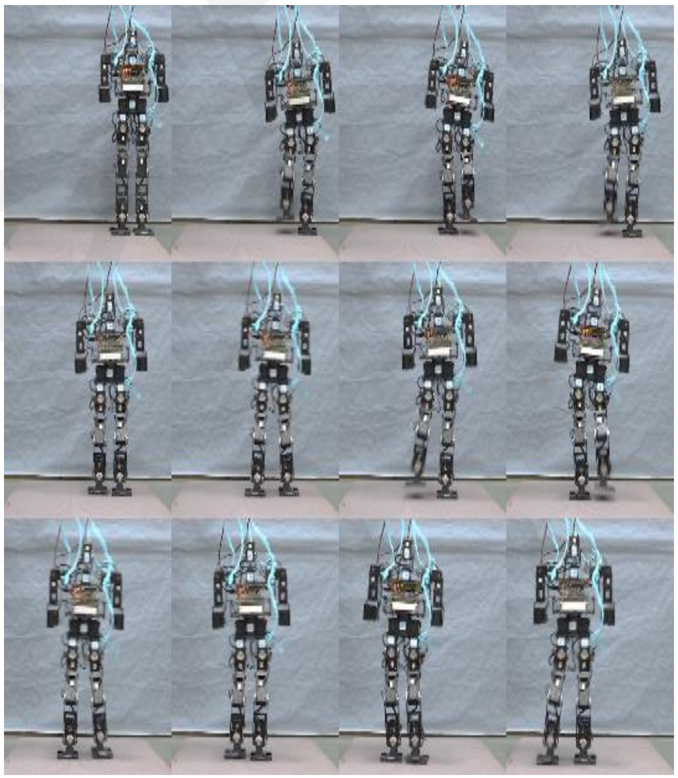


Fig. 7 Screenshots from lateral experiments based on the COM trajectory-planning method.

Simulation and Experimental Validation

Lateral walking with resistance to random impulse disturbance

Despite the presence of external random impulse force varying within [-10, 10] N, the designed disturbance-resistant control method based on bidirectional coordination promptly adjusted the foothold position to counteract the effects of the external force.

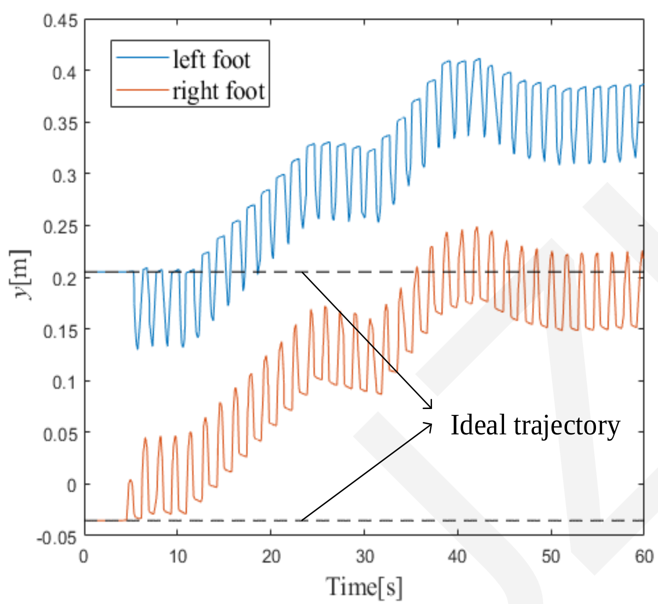


Fig. 8 Simulation results of lateral walking with resistance to random impulse disturbance based on foot placement and COM state feedback compensation.

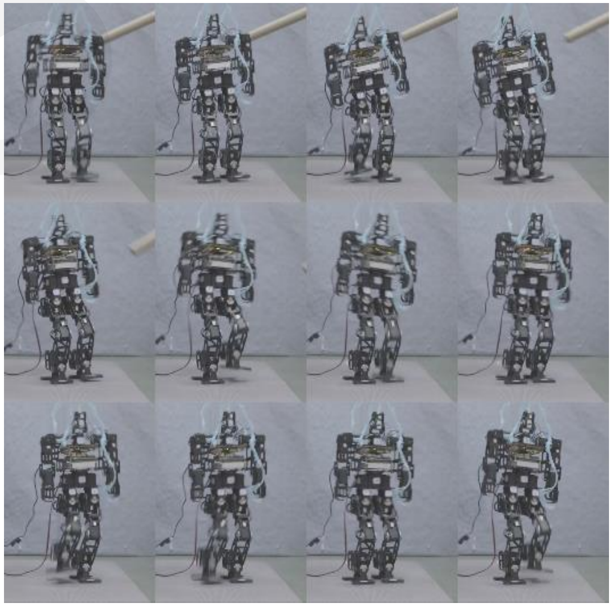


Fig. 9 Screenshots from experimental video of lateral walking with resistance to random impulse disturbance based on foot placement and COM state feedback compensation.

Conclusions

- **The improved centroid trajectory planning method for bipedal robots can be used to achieve flexible walking in small bipedal robots, including side-stepping, diagonal walking, and in-place turning.**
- **Based on the proposed anti-disturbance feedback compensation control method, small bipedal robots can maintain stability without falling when subjected to random impulsive forces during side-stepping, diagonal walking, and in-place turning.**