Forced bipedal walking model that mimics COP excursion reproduces next step generation

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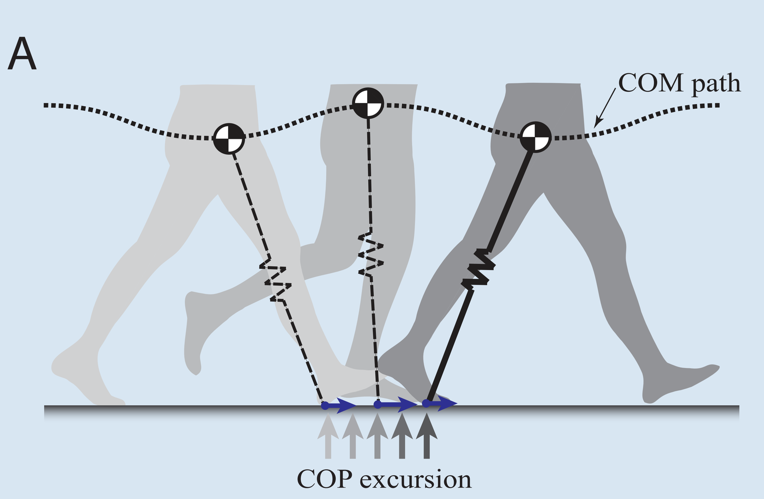
1 Introduction

- In recent study, a compliant inverted pendulum was proposed to explain basic characteristic human gait dynamics.
- However the previous model could not reproduce the heel-to-toe center of pressure excursion (COP) observed in human due to a single point contact foot of the model.
- Moreover, previous bipedal walking models handle the touch down angle as a criteria for next step generation which empirically appeared to be the resultant motion depending on the gait speed.
- In this work, we proposed a walking model applied with a forcing function at the ground contact point that generates COP excursion.
- To perform gait simulation of the proposed model, we also introduced a new step generation criteria to be the reach of COP at the metatarsal of stance foot.

2 The forced pendulum model

- The key concept underlying forcing pendulum is that the oscillation period of leg and COP excursion period concur. To explicitly represent the relationship, we introduced COP excursion as a sinusoidal function with amplitude of human foot length



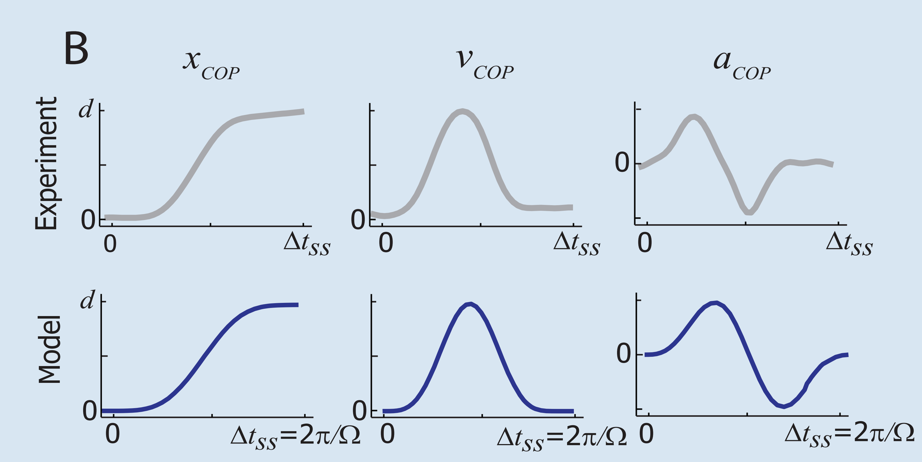
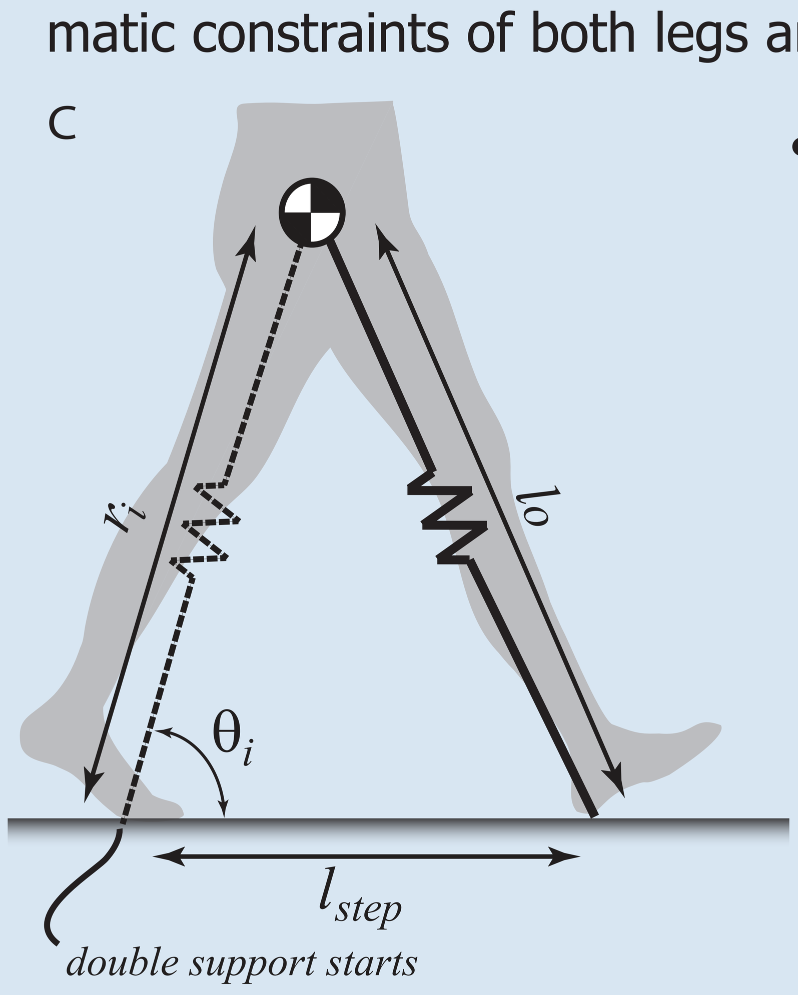


Fig. A: The forced compliant bipedal model with a pivot that follows a sinusoidal function with period of 2π. **Fig. B:** The empirical (top) and the simulation (bottom) trajectories of COP location, velocity and acceleration (from left to right) during single leg stance. d and Δtss(=2π/W) represents length between heel and metatarsal and single support duration respectively.

- Additionally, we introduced a criterion for next step generation. As a reflection of the experiment observation that COP remains at metatarsal until the next heel strike [4], we set our model to shift from single to double stance phase when the COP trajectory completes a cycle and the next step position and strike angle are decided by kinematic constraints of both legs and orientation.



- In our model, when the trajectory completes a cycle, the COP saturates at the location of metatarsal. Then the next heel strike angle and step length are decided by the kinematic constraints formed by stance leg length, angle and fully stretched swing leg.

Fig. C: The next step generation scheme. The triangular kinematic constaraint determines next heel strike angle and length of the step ($l_{step} = r_i \cos\theta_i + \sqrt{l_0^2 - r_i^2 \sin^2\theta}$)

3 Experiment

- 8 healthy young subjects (7 male and 1 female, 23.5 years ± 2.07) with no history of walking deficit volunteered for this study.
- All experiments perforemd according to KAIST IRB protocols.
- Subjects were instructed to walk on a 12 meter long walkway at 5 different walking frequency arbitrarily cued by metronome.
- The GRF and COP information are measured by AMTI force measurement plate. Joint and COM location information are obtained by Motion analysis motion capture system.
- Ground reaction forces and kinematic information were collected with 200Hz sampling frequency, and filtered using Butterworth 5th low-pass filter with 5Hz cutoff frequency.

4 Results

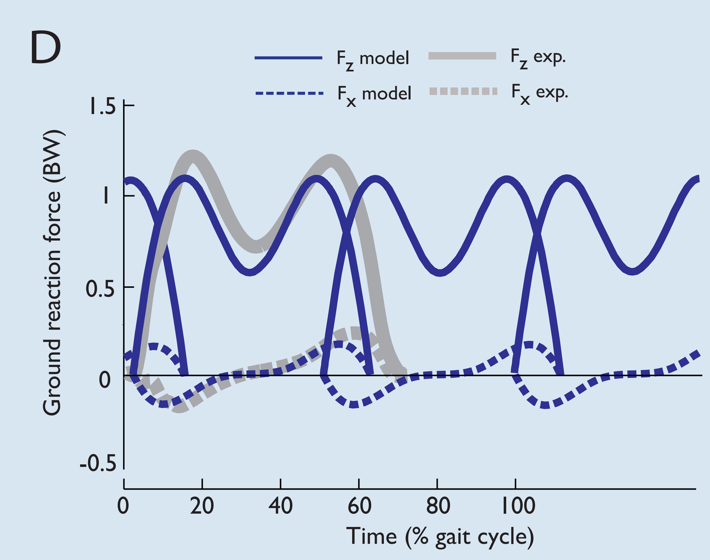


Fig. D: The GRF trend of experiment and simulation at 1.4 m/s. The force is normalized by body weight and time is normalized by the period for a gait cycle.

- The model simulation showed COP excursion and ground reaction force (GRF) trend similar to experimental observations.
- The limit cycles are found at high speeds (<1.9 m/s) whereas in point contact compliant model the maximum walking speed was limited at 1.5 m/s.
- This result is more consistent with human as the shift from walking to running occurs at 2.3 m/s. From parameter study of simulation, we found that limit cycles at higher velocity tend to have greater spring constant, and less Dtss.

5 Conclusions

- The parameter study of simulation shows somewhat optimistic results for explaining the velocity-step length relationship but our study is yet limited for we require another hypothesis for choosing one gait strategy among from others.
- The fact that we found many combinations of initial conditions that converge to limit cycles or walk multiple steps without falling, although not necessarily in limit cycle, might suggest robustness of our model.

6 References

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