Efficiency and kinetics analysis of powered walking model with different load connection forms

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1 Introduction

It has been proved that some load carrying devices could improve walking performance for humans and robots. The key idea of these devices is to change the connection form between the body and the load. The purpose of this study is to compare the effect of load connection forms on the toe-off efficiency and kinetics.

2 Step-to-step Transition Analysis

We extended the powered walking model [1] and four load connection forms including rigid connection (RIC), springy connection (SPC), swingy connection (SWC) and springy and swingy connection (SSC) are modeled as shown in Figure 1. The load of RIC model is rigidly attached to the body. The load of SPC is attached to the body with a spring. It can oscillate freely in the vertical direction while it has the same kinematic state with the body in the horizontal direction. The load of SWC is linked to the body with a rigid rope. SSC combines SPC model and SWC model. All models are actuated only by toe-off impulse **P** immediately before heel strike, and the **P** is along the trailing leg. Step-to-step transition is instantaneous.

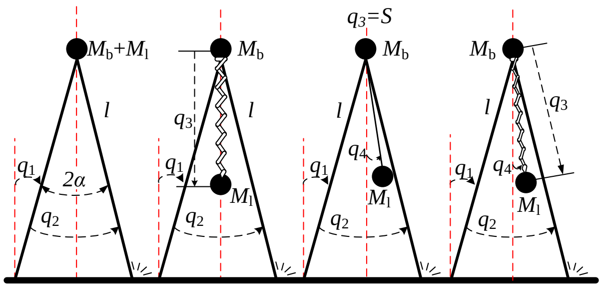

Figure 1: Transition moment of four load connection forms. q_1 denotes stance leg angle and q_2 denotes swing leg angle. q_3 denotes spring length and q_4 denotes swing angle of load. Original spring length and rope length are both S. Leg length is l and the step angle is 2α. Body mass is M_b, and load mass is M_l

When periodic walking, there is a certain relationship between body velocity just after transition $\|\mathbf{v}^+\|$ and **P**. We can obtain this by using conservation of angular momentum and impulse-momentum equations. The analytical results are shown in Table 1.

At transition moment, different connection forms will exert different influence on body, which leads to different $\|\mathbf{v}^+\|$ with the same **P**. We found SPC and SSC have greater $\|\mathbf{v}^+\|$ than RIC, and this means the spring can improve the efficiency of instantaneous transition. For SWC, q_4 at the transition moment will also affect the result and the influence obeys a certain equation. q_4 is naturally very small (load is directly below the body) at that moment, and $\|\mathbf{v}^+\|$ equals $\|\mathbf{P}\|/[(M_b+M_l)\tan\alpha]$ if we assume q_4=0.

Table 1: Theoretical relationship between $\|\mathbf{v}^+\|$ and $\|\mathbf{P}\|$

Model	RIC and SWC (q_4=0)	SPC and SSC
$\|\mathbf{v}^+\|$	$\|\mathbf{P}\|/[(M_b+M_l)\tan\alpha]$	$\|\mathbf{P}\|/(M_b\tan\alpha)$

3 Average Walking Speed and GRF

The interaction between load and body during the single stance phase can also influence walking, and this interaction is difficult to measure analytically. Therefore, we performed simulations to obtain average walking speed and use this speed as an overall evaluation.

We expected the sprung load will slow down the system during the single stance phase, as a result, there will be smaller variance among average walking speeds of models than after-transition body velocities. However, the fact is the springy connection increase average walking speed more than after-transition body velocity. With the increase of step angle, the speed ratio of SPC model and RIC model is getting greater and greater than $(M_b+M_l)/M_b$ which is the analytical ratio of after-transition body velocity between these two models. This may due to the character of the inverse-pendulum model.

Connection forms also strongly affect GRF. Models with spring have obviously greater peak of single stance GRF while smaller GRF around the transition moment. This may lead to the improvement of efficiency.

4 Conclusion

Analysis of walking with different load connection forms shows the springy connection can increase the after-transition body velocity compared with ordinary RIC model, for the springy connection can reduce burden around the transition. Influence of swingy connection is naturally small and affected by swing angle at the transition moment. It's possible that we can control the load swing to make it more beneficial. Simulation results shows that springy connection can actually increase average walking speed even more than the after-transition velocity, and the GRF decreases around transition, which proves the burden reducing effect of springy connection.

References

[1] A. D. Kuo, "Energetics of actively powered locomotion using the simplest walking model", ASME J. Biomech. Eng. 124(1)(2002), 113-120.