Conceptual models for real-world locomotion

Andre Seyfarth, Lauflabor Locomotion Laboratory (www.lauflabor.de) , TU Darmstadt, Germany

***Abstract*—During human and animal locomotion, the dynamics of the body can be represented with the help of simplified biomechanical models, such as the spring-mass model (often described as spring-loaded inverted pendulum, SLIP model). In this model, it is assumed that the force generated by each limb resembles that of a linear spring. Furthermore, it is assumed that force generated by the leg mainly acts in leg axis, e.g. the connecting line between contact point (foot) and body (center of mass). Finally, the contact point at the ground is considered fixed during ground contact. Although all of these assumptions are considerable simplifications compared to most biological and artificial legged systems, this gait model provides a useful template for developing more detailed gait models taking leg segmentation (thigh, shank, foot), non-elastic leg properties (e.g. damping, variable leg spring properties), upper body (trunk), neuro-muscular properties (e.g. reflexes) and multiple legs (e.g. bipedal configuration) into account.**

Keywords: Legged locomotion; conceptual model; template; biomechanics; walking robot.

I. Gait Models with Rigid Legs

In the "simplest walking model" [1], bipedal legged locomotion is described with a pair of rigid legs supporting a body represented by a point mass. This model provides a theoretical basis for a series of passive dynamical walking robots [2]. These robots exhibit some mechanical stability and high energy efficiency (partially even better than in human walking). Theoretically, it is even possible to predict walking and running gaits for rigid legs with extremely high leg forces at transitions between contact and air phases [3]. Although mathematically appealing, the dynamics of these gait models and robots are considerably different to human and animal locomotion. This gap can be closed (or at least largely reduced) when taking compliant leg properties into account [4].

II. Models Based on Spring-Like Leg Function

Compliant leg function is a key property in biological limbs, which results from elastic structures (e.g. tendons) recruited by interactions between body mechanics, muscle mechanics and neural control. Assuming a spring-like leg function in a bipedal SLIP model [4] leads to predictions of large regions of stable walking and running for proper tunings of leg stiffness and leg angle of attack to locomotion speed (system energy). In contrast to previous models relying on rigid legs, this model also shows similarities between predicted and experimental ground reaction forces in both gaits. Another advantage of this model is it's ability to be represented with larger levels of details (Fig. 1) regarding body structure (number of legs [4], leg segmentation, foot [5], trunk [6]), mechanical properties (leg masses, variable leg spring [7]) and neuro-muscular control (e.g. muscle-reflex schemes).

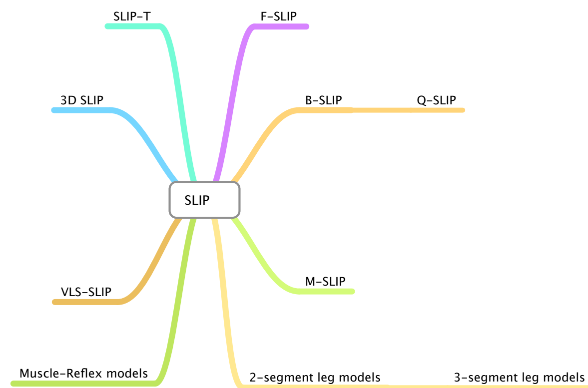

Figure 1: Hierarchy of conceptual gait models based on the SLIP template. (F=foot, B=bipedal, Q=quadrupedal, M=leg masses, T=trunk, VSL=variable leg spring).

III. Outlook

In the future, these model extensions need to be considered more systematically in order to better understand their inter-relations and to design more advanced models for biological or technical locomotor systems. Here, the focus is not only on a more realistic representation of locomotor mechanics but - and equally important - on a model-based design of biologically plausible control schemes for legged systems of different architectures.

References

[1] Garcia, M., Chatterjee, A., Ruina, A., & Coleman, M. (1998). The simplest walking model: stability, complexity, and scaling. Journal of biomechanical engineering, 120(2), 281-288.

[2] Collins, S., Ruina, A., Tedrake, R., & Wisse, M. (2005). Efficient bipedal robots based on passive-dynamic walkers. Science, 307(5712), 1082-1085.

[3] Srinivasan, M., & Ruina, A. (2006). Computer optimization of a minimal biped model discovers walking and running. Nature, 439(7072), 72-75.

[4] Geyer, H., Seyfarth, A., & Blickhan, R. (2006). Compliant leg behaviour explains basic dynamics of walking and running. Proceedings of the Royal Society B: Biological Sciences, 273(1603), 2861-2867.

[5] Maykranz, D., & Seyfarth, A. (2014). Compliant ankle function results in landing-take off asymmetry in legged locomotion. Journal of Theoretical Biology.

[6] Maus, H. M., Lipfert, S. W., Gross, M., Rummel, J., & Seyfarth, A. (2010). Upright human gait did not provide a major mechanical challenge for our ancestors. Nature communications, 1, 70.

[7] Riese, S., & Seyfarth, A. (2012). Stance leg control: variation of leg parameters supports stable hopping. Bioinspiration & biomimetics, 7(1), 16.