11º CONGRESSO NACIONAL DE BIOMECÂNICA
A. P. G. Castro, C. Pina, P. R. Fernandes, C. Santos, J. Folgado & A. Amaro (Eds)
Sesimbra, Portugal, 21-22 de Fevereiro, 2025

TRIANGULAR LEG COORDINATES FOR WALKING GAIT

André S. Carvalho, Miguel A. Botto e Jorge M. Martins

IDMEC/Instituto Superior Técnico, Universidade de Lisboa,

Av. Rovisco Pais, 1049-001 Lisboa, Portugal.

andre.s.carvalho@tecnico.ulisboa.pt; ayalabotto@tecnico.ulisboa.pt; jorgemartins@tecnico.ulisboa.pt

KEYWORDS: Biomechanics, Locomotion, Modeling, Control

1 INTRODUCTION

In a previous work, a controller was devised in order to model the dynamics of running athletes [1]. Such locomotion model is formulated as an explicit control of the ground reaction force in order to drive the contact force towards a compliant force that is able to stabilize the multibody system into a running gait. The controller poses a limitation, through which only a single contact point is able to be modelled (at the ball of the foot). The present work aims at overcoming this limitation by extending the control to multiple contact points, with the goal of modeling the dynamics of bipedal walking. Such a model is relevant to further the understanding of how the whole-body dynamics generate locomotion. It is envisioned that such a model may be employed to rectify pathologies in the simulation loop, in order to obtain solutions that further the design of assistive locomotion devices.

The present work separates itself from other similar approaches [2] by allowing a free progression of the pressure center, which emerges here from the impedance behavior of stance, instead of a positional specification. To achieve this, a set of leg coordinates is introduced to describe and control the motion of the stance leg. Finally, it will be shown how these coordinates may be employed to describe a spring-mass template to model the external dynamics of walking.

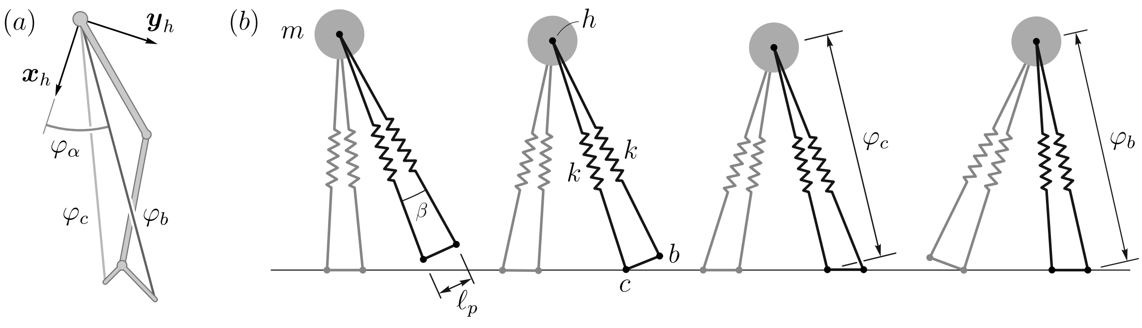

Figure 1. (a) Triangular leg coordinates. The φ_α coordinate is measured with respect to the torso orientation, which is not illustrated. (b) Triangular spring-mass model. Illustrated from simulation (Fig. 2).

2 TRIANGULAR LEG COORDINATES

It is here suggested to use a set of coordinates such as the one illustrated in Fig. 1(a). The choice of coordinates is performed in parallel with the choice of the impedance model (Fig. 1b). Here, the φ_b coordinate measures the distance between the hip and the ball of the foot, while φ_c measures the distance between the hip and the calcaneus. Another coordinate, φ_α, measures the angle between the torso and the segment connecting the hip and ball. This fully defines the leg's configuration. In particular, if the previous coordinates are gathered as $\boldsymbol{\varphi} = \boldsymbol{\varphi}(\boldsymbol{q})$ and $\boldsymbol{q}$ are the revolute joint coordinates of the leg, then $\dot{\boldsymbol{\varphi}} = (\partial\boldsymbol{\varphi}/\partial\boldsymbol{q})\,\dot{\boldsymbol{q}}$ and $(\partial\boldsymbol{\varphi}/\partial\boldsymbol{q})^{-1}$ exists in a range of anatomically valid configurations.

The advantage of this formulation is that an impedance control scheme can be easily employed over these coordinates, which is useful in the modeling of locomotion systems by means of a multibody system. This fact is owed to the kineto-static duality, which is to say that generalized forces, $\boldsymbol{\xi}_{\varphi}$, along the triangular set are related to joint torques, $\boldsymbol{\xi}_q$, through $\boldsymbol{\xi}_q = (\partial\boldsymbol{\varphi}/\partial\boldsymbol{q})^{\top}\,\boldsymbol{\xi}_{\varphi}$.

To illustrate the deployment of the triangular leg coordinates, it is here presented a modified version of the spring-mass model/template for locomotion [3]. As illustrated in Fig. 1(b), each leg is modeled by a pair of springs, with stiffness k, constrained by the fixed length of the foot's sole, denoted as ℓ_p.

3 Discussion and Conclusion

The present solution, illustrated in Fig. 2, presents a smooth progression of the pressure center and also a force profile which is similar to a walking gait. To note, the force profile shows an uncharacteristically low vertical force during midstance. Also, the force profile is not smooth (non-differentiable). The former issue may be overcome by exploring a wide range of stable solutions, while the latter may be solved by exploring alternate impedance models along the leg coordinates. That is, impedances which are not necessarily a constant stiffness.

The present approach may be extended to three dimensions by inclusion of another length coordinate for stance and two additional coordinates for leg orientation. Again, an appropriate impedance template may be developed in parallel with the choice of coordinates.

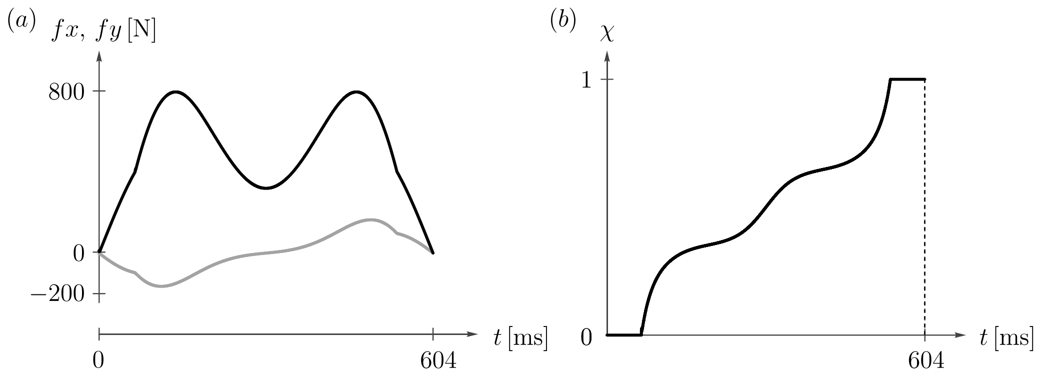

Figure 2. Stable periodic solution, with $m = 75\ kg$, $\varphi_c(0) = \varphi_b(0) = 1\ m$, $k = 9 \times 10^3\ [N/m]$ and $\ell_p = 15\ cm$. (a) Force profile along x (gray) and y (black). (b) Pressure center, from calcaneus ($\chi = 0$) to ball ($\chi = 1$).

Acknowledgements

The authors acknowledge Fundação para a Ciência e a Tecnologia (FCT) for its financial support via the projects LAETA Base Funding (DOI: 10.54499/UIDB/50022/2020). This work was supported by FCT/MEC through national funds (PIDDAC), under SFRH/BD/137986/2018.

References

[1] Carvalho, A. S., & Martins, J. M. (2018). Bipedal running through imposition of a stabilizing contact force. In 2018 IEEE International Conference on Autonomous Robot Systems and Competitions (ICARSC) (pp. 42-47). IEEE.

[2] Hyon, S. H., & Cheng, G. (2006). Passivity-based full-body force control for humanoids and application to dynamic balancing and locomotion. In 2006 IEEE/RSJ International Conference on Intelligent Robots and Systems, 4915-4922.

[3] 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.