How to achieve stable trotting?

Martin Groß, Jürgen Rummel and André Seyfarth
Lauflabor Locomotion Laboratory, University of Jena, Dornburger Str. 23, 07743 Jena, Germany,
email: martin.gross@uni-jena.de, web: www.lauflabor.de

SUMMARY

Trotting is a natural gait of quadrupedal animals. In this study we investigated how trotting can be stabilized. Stability was analyzed using an enhanced spring-mass model and gait parameters were taken from dog experiments. Dogs take advantage of compliant leg dynamics but a preparation for ground contact is necessary. We found that a combination of swing-leg retraction and leg stiffening shortly before touch-down is necessary for stable trotting.

INTRODUCTION

Animals use different gaits for locomotion at different speeds (e.g. walking, trotting, galloping) while the legs act like mechanical springs [1]. The trotting gait of dogs seems to be a very smooth gait and is used for a wide range of velocities. From a mechanical point of view, trotting is closely related to human running which can be described by a simple spring-mass model predicting self-stability in walking and running [2, 3].

Here we analyze strategies of stabilizing dog trotting by taking an additional degree of freedom, i.e. the body pitch, into account.

METHODS

We conducted experiments on dogs (*Canis lupus* f. *familiaris*, Airedale Terrier) trotting at 2 m/s on an instrumented treadmill (with integrated Kistler force sensors and external Qualisys motion capture system) and analyzed spatiotemporal and dynamic parameters.

Based on these parameters we built a simple model of the dog, which consists of two massless leg springs connected to the anterior and posterior ends of the rigid body (Fig. 1). Self-stability was analyzed by using the steps-to-fall method [2] and appropriate control strategies [4] were identified using Poincaré return maps.

RESULTS AND DISCUSSION

Experiments show that trotting is a running gait where the legs act like springs. This spring-like leg behaviour is more pronounced in the front limbs than in the hind limbs. Simulations indicate that a speed of 2 m/s is not sufficient to achieve self-stable trotting for fixed angles of attack α_0. In a second step, swing-leg retraction [4] was applied to stabilize gait. This motion is also observed in dog trotting (Fig. 2). Based on the experimentally identified trotting solution we found that swing-leg retraction may stabilize locomotion but the predicted retraction speed is lower than that of dogs ($\omega_{FL} \approx 250$ deg/s, $\omega_{HL} \approx 270$ deg/s). Introducing a combination of swing-leg retraction and leg stiffening in preparation for ground contact is suited best to stabilize the observed trotting gait (Fig. 2).

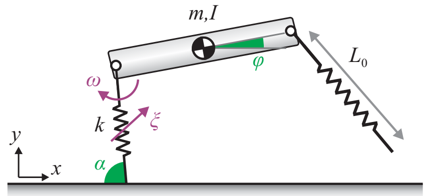

Figure 1: Conceptual model of a quadrupedal animal.

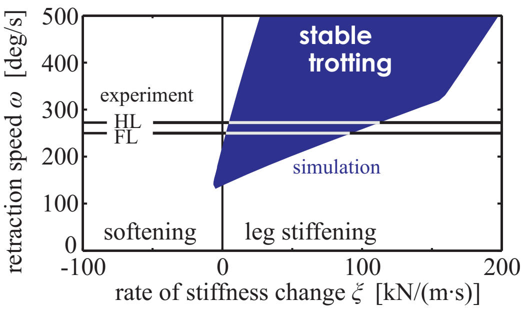

Figure 2: Combinations of swing-leg strategies leading to stable trotting (blue area). Horizontal lines represent experimental data for hind legs (HL) and front legs (FL).

The swing-leg retraction is mainly performed by proximal leg segments [5] and could be enhanced by joint flexion or extension. The non-linear relationship between joint torque and leg force in segmented legs further supports stability in bouncing gaits [6]. The model predicted a leg stiffening mechanism, which might be done by increasing muscle activity before touch down [7].

In future, these gait and stability analyses on simplified dog models will be extended to other gait patterns (e.g. walking) also including the effects of a compliant trunk.

REFERENCES

1. Blickhan R, *J Biomech* **22:** 1217-1227, 1989
2. Seyfarth A, et al., *J Biomech* **35:** 649-655, 2002
3. Geyer H, et al., *Proc R Soc B* **273:** 2861-2867, 2003
4. Blum Y, et al., *AMS*, Kaiserslautern, Germany, 2007
5. Fischer MS, Blickhan R, *J Exp Zool* **305A:** 935-952, 2006
6. Rummel J, Seyfarth A, *Int J Robot Res* **27**: 919-935, 2008
7. Tokuriki M, *J Jap vet Sci* **35:** 525-533, 1973

ACKNOWLEDGEMENTS

The authors thank Prof. Dr. Martin S. Fischer. This study was supported by the DFG, the GKF and the EU-LOCOMORPH Project.