Comparison of feed-forward control strategies for hopping model with intrinsic muscle properties of different complexities

Dóra Patkó*, Ambrus Zelei** and Giuseppe Habib*

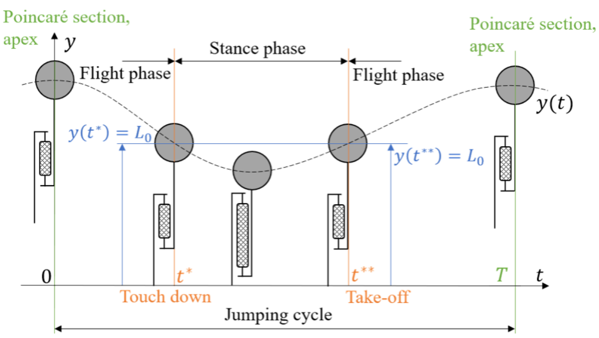
*MTA-BME Lendület "Momentum" Global Dynamics Research Group, Department of Applied Mechanics, Budapest University of Technology and Economics, Budapest, Hungary,
Patkó ORCID 0000-0001-7594-1882, Habib ORCID 0000-0003-3323-6901

**Department of Whole Vehicle Engineering, Audi Hungaria Faculty of Automotive Engineering, Széchenyi István University, Győr, Hungary, Zelei ORCID 0000-0002-9983-5483

Abstract. In the simplest manner, hopping motion can be modelled by a spring-mass system, resulting in piece-wise smooth dynamics with marginally stable periodic solutions. Let us consider a Hill muscle instead of the spring. This way asymptotically stable periodic motions can occur. The activation level of the muscle is determined by feed-forward control. The physiological background of such control is the central pattern generators found in the spinal cord. The activation level function is chosen in a closed-from such a way that force time-history during periodic motion is symmetrical. In this study, the stability and the dynamical integrity of six different models with various muscle complexities (force-length relations: constant, linear, Hill-type; force-velocity relations: linear, Hill-type) are analysed through the monodromy matrix and the local integrity measure. These models are compared to similar systems with numerically optimised activation level functions found in the literature.

Introduction

Reductionist approach is used to have a better understanding of the core properties of vertical hopping motion. A 1D model is considered with a simplified Hill type muscle, consisting only of the contractile element (CE), as shown in Fig. 1. Haeufle et al. [1] established that, for this model, the intrinsic properties of the CE have stabilizing effect, and for asymptotic stability the force-velocity relation (f_v) has to be at least linear. They optimized the activation level function through genetical algorithm.



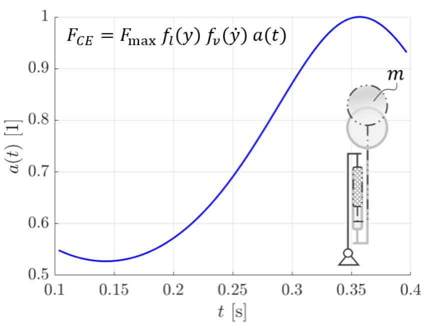


Figure 1: 1D hopping model and the closed form activation level function during the stance phase for linear force-length ($f_l(y)$) and force-velocity ($f_v(\dot{y})$) relations. The force output of the CE depends on the theoretically achievable maximum force value ($F_{\max}$), the momentary activation level ($a(t)$) and the intrinsic f_l and f_v relation of the muscle.

In this study, the muscle activation is calculated in closed form resulting in symmetric force time-history. The solution is optimized for the same fitness function used in [1]. The stability of the periodic orbits are determined by the eigenvalues of the monodromy matrix, which is calculated as described in [2]. The robustness of stable orbits are characterized by the local integrity measures (LIM), calculated exploiting the DynIn toolbox [3]. The solutions for the six different systems are compared through their multipliers and LIM values to find which muscle intrinsic relation is the most beneficial, and to see whether symmetric motions, occurring from the closed form activation function, has any advantage to asymmetric ones, as found by Haeufle et al [1].

Results and discussion

According to our results, the asymmetric solutions (AS), determined in [1], have better performance than the symmetric solutions (SS), which are calculated with closed form activation function. This means that the AS with approximately 2 Hz jumping frequency have higher jumping heights. In case of the AS, the systems with non-linear f_v have faster convergence than the ones with linear f_v. For the SS, the fastest convergence to the stable periodic orbit is obtained with the linear force-length relation (f_l), while the f_v has no significant effect on the convergence speed. All the AS have oscillatory convergence. Systems with linear f_v have the highest LIM values, and, in general, AS have higher LIM values than SS.

References

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