Frequency Matching: Optimizing Bio-Inspired Robotic Legs with SLIP-like Dynamics

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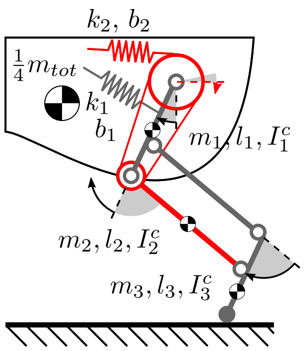

(a) Pantograph Leg

(b) DLR bert

Fig. 1: Link parameters of the three-segmented pantograph-leg mechanism *(adapted from [5])* which will be implemented into DLR bert.

The spring-loaded inverted pendulum (SLIP) model [1] and its extensions for bipedal [2] and quadrupedal [3] systems model the dynamics of biological legs sufficiently. A rotational hip spring [4] can be incorporated so that leg swing is also a passive dynamic motion. Due to the massless leg spring, this template model can not directly be transferred into a physical robotic leg. Furthermore, efficient locomotion in difficult environments calls for segmented legs instead of prismatic ones. With the goal of implementing such a segmented leg, we here extend the work of [5], where the SLIP dynamics were embedded into a 3-link leg with a pantograph mechanism (Figure 1a). We will use this as a basis for the development of a future generation of the robotic quadruped DLR bert (Figure 1b).

However, this approach results in a design with extremely high link inertias due to a constraint on the link COM positions. Moreover, this technique only constrains the ratio of physical *link* parameters to one another, while overall *leg* properties like resting length or stiffness can be chosen freely.

To overcome these limitations, the constraints on the link COM are relaxed. We propose an optimization approach called *Frequency Matching* to design physical robotic legs which are similar to nature in terms of dynamics and physical dimensions. Here, we explicitly account for the scale effects between body weight and leg design, which are found in biology [6]. These provide reasonable starting values for the physical dimensions of the *leg*. Example parameters for limb design of a quadruped with total mass of $m_{tot} = 3$ kg can be found in Table I. The corresponding leg stiffness amounts to $k_{leg} = 1.49$ kN m^{-1} [7].

The physical *link* parameters are optimized so that the leg swing frequency of the linearized system matches the natural swing frequency given in Table I. The requirement of SLIP-like dynamics provides the conditions used to compute the *link* parameters. The result is the specification of a robotic leg which matches the swing frequency of the natural leg, while staying reasonably close to the physical limb dimensions suggested by nature and having a SLIP-like dynamic. With these legs, we aim at building a robotic quadruped able to implement efficient dynamic locomotion.

At the **Dynamic Walking Conference** I would additionally like to discuss the importance of leg swing frequency to locomotion, as well as the influence of intrinsic dynamics versus control in locomotion.

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TABLE I: Physical dimensions of the leg of a 3kg quadruped suggested by scale effects found in biology [6].

Leg Parameters	
Leg mass	$m_{leg} = 0.270$ kg
Passive leg length	$l_o = 0.227$ m
Distance leg COM to hip	$c_{leg} = 0.062$ m
Moment of inertia	$I_{leg} = 0.00182$ kg m^2
Natural swing frequency	$f_{swing} = 1.45$ Hz

References

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