Compliant Leg Design for a Quadruped Robot

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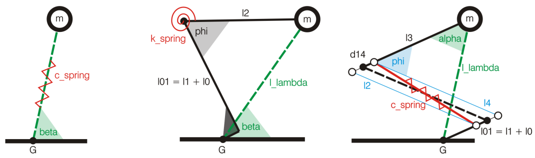
A. Summary

We present the quadruped, compliant robot system Cheetah (Fig. 2(a)). Main features are light-weight, retractable, passive compliant two and three segmented legs. Knee joints are actuated using RC servo motors mounted proximal, force transmission is achieved by means of a Bowden cable system [1]. The leg design was loosely inspired by legs of mammalian animals, i.e. that of a cat. It was also influenced by the spring-mass model representation [2]. Compliant prismatic legs show an intrinsic robustness for their angle of attack [2], they have a stability region. If the leg design is changed into a two segmented leg with a specific linear torsional spring, the leg stiffness k_{leg} becomes nonlinear (Fig. 2(b) blue line), similar to that of a declining spring. The influence of the nonlinearity shifts and increases the stability region [3]. We introduce a *three segmented, compliant pantograph leg* (Fig. 1(c)), its leg stiffness k_{leg} is also non-linear and can be described as piece-wise linear (Fig. 2(b) black lines). Two-step compression springs roughly resemble this behavior. However the nonlinear k_{leg} behavior of our pantograph leg emerges from a linear spring and *geometric parameters* such as leg segmentation ratio and placement of the spring fixation (d_{14} in Fig. 1(c)). Choosing a desired leg segmentation ratio during the leg design process changes e.g. the magnitude of the stiffness constant at higher leg compression (Fig. 2(b), solid and dashed black line). If d_{14} is altered, the point of discontinuity is completely shifted (Fig. 2(b), solid black line and dot-and-dashed black line). Latter can be used to create an *Adaptive Compliant Pantograph* leg, by on-line changing the switching point e.g. by a motor moving the fixation point of the spring. Often a pre-tension is applied to change spring stiffness, however this only *shifts* the new working area along the old stiffness trajectory. By e.g. changing the spring fixation point of the pantograph leg (enlarging d_{14}) we can *create a completely new stiffness trajectory*, and enventually adapt to different load conditions per leg due to a gait change.



(a) Prismatic leg (b) 2 segmented leg (c) 3 segmented leg

Fig. 1. Schematic presentation of compliant legs; (a) prismatic, (b) two segmented, (c) three segmented pantograph.

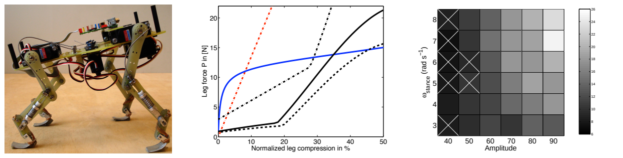

(a) Cheetah robot (b) k_{leg}-behavior (c) Systematic search

Fig. 2. (a) Quadruped robot Cheetah with compliant three segmented legs. (b) k_{leg} for different leg designs (1) red dot-and-dash line: prismatic leg (2) blue line: two segmented leg (3) black dashed line pantograph leg with unequal segmentation (4) black full line: pantograph leg with equal leg segmentation (5) black dot-and-dash line: same equal segmentation as before, but bigger d_{14}. (c) Experimentally measured velocities for walking gait, systematic search over two CPG parameter. Maximum walking speed $v = 0.25\,\mathrm{m/sec}$, ~ 1 *bl*/s.

B. Results and Discussion

We are currently evaluating both the pantograph three segmented leg and the two segmented leg. Among others we check t_{stance} times for different gaits [1], using the spring-mass model with according linear and nonlinear leg stiffness values. We aim at energy efficiency during the gait cycle, and natural leg-frequency behavior close to the frequencies required for running our quadruped robot at different gaits. A CPG Network [4] was implemented to generate motor trajectories for several gaits, it can also incorporate sensor information and change its behavior accordingly. Cheetah robot was performing successfully two gaits: walk and pace at $25\,\mathrm{cm/s}$ and $11\,\mathrm{cm/s}$, respectively. A better understanding on the influence of segmentation and spring parameters for the dynamic behavior of the robot will eventually enable us to perform gaits also for higher velocities. Compared to other quadruped robots [5], [6], [7] Cheetah is still relatively slow.

References

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