Oncilla Robot—A Light-weight Bio-inspired Quadruped Robot for Fast Locomotion in Rough Terrain

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Abstract: On the hardware level, we are proposing and testing a bio-inspired quadruped robot design (*Oncilla robot*), based on light-weight, compliant, and three-segmented legs. Our choice of placing the compliance such that it is spanning two joints enforces a non-linear spring stiffness. Based on the SLIP-model assumption, we compare progressive and degressive stiffness profiles against a linear-leg stiffness. To facilitate fast and throughout testing also of control approaches we have created a robot model of *Oncilla robot* in simulation (in Webots [1], a physics-based simulation environment). Here we are presenting new simulation results based on open-loop-central pattern generator (CPG) control and PSO-optimization of the CPG parameters. Our quadruped robot is equipped with passive compliant elements in its legs, and we apply two different strategies to make use of the legs' compliance during stance phase. This enables us to find stable trot gait patterns propelling the robot up to 1 m/s (more than four times the robot's leg length), depending on the applied stance phase leg-strategy. Different trot gait patterns emerge, and resulting trot gaits are variable in stability (tested as robustness against external perturbations) and speed.

Keywords: Quadruped robot, compliant three-segmented leg design, bio-inspired, fast locomotion, stability, CPG.

1. MOTIVATION AND HARDWARE

By designing, building and testing a robust, compliant, light-weight and versatile quadruped robot we want to provide a bio-inspired platform for development and testing of different approaches to motion control (e.g. locomotion and reaching, or stepping). Hence we are developing a new version of our previous robot *Cheetah* [2]. Both the physics-based simulated version and the in-construction version of *Oncilla robot* (named after a small-sized feline animal from South-America) are based on a mammalian animal, of approximate size and weight of a house cat *(Felis catus)*. *Oncilla robot* features three segmented legs both for its front and hind limbs, similar to our previous quadruped robot *Cheetah*, Fig. 1(a). Quadruped, mammalian animals have a distinct three segmented limb construction both for their front and hind limbs (front limb: if the scapula is included [3-6]). As it has been suggested by [7], Oncilla robot's limbs are panthographic. Hence proximal and distal limb segment are connected with a parallel mechanism, see Fig. 1(a). This keeps e.g. thigh and foot segment of the hind limbs parallel at all times, and resembles the animals leg segment behaviour for most of a step cycle. The robot's pantographic legs are equipped with a passive spring mechanism. The orientation and the type of springs used (extension springs) classifies the robot's leg as a passively extending, gravity loaded, compliant leg. Each of *Oncilla robot*'s legs is equipped with three actuators. The proximal actuator is responsible for leg protraction and retraction. The second actuator is flexing the two mid-joints by a cable mechanism. Extension of mid-limb joints is only possible by the passive, linear spring. The third actuator will be responsible for the ablation DOF. For some more details please refer to [2].

2. THREE-SEGMENTED LEG DESIGN

The combination of a three-segmented leg design and a two-joint spanning compliance produces a non-linear leg force behavior for *Oncilla robot's* legs. We checked the self-stability regions of different leg segmentation ratios for our leg design (λ from 0.1 to 0.5, where λ is the segmentation ratio of the mid segment to the leg length). We found that we can shift the leg force characteristics from a progressive leg force, over a mostly linear leg force, into a degressive leg force profile (Fig. 2). A SLIP-model [8] of a single three segmented leg with the corresponding *altered* stiffness profile is checked for *self-stability* (Fig. 2). Please note that the original SLIP model is assuming only linear leg forces, i.e. this would correspond to a prismatic leg design. Black areas in Fig. 2 indicates stable solutions for the pantograph leg, for comparison the stable area for the linear SLIP model is plotted in grey. The second row of Fig. 2 shows the leg force for a relevant range of the virtual leg. For $\lambda = 0.1$ (progressive leg force profile) the stable area is decreased. For $\lambda = 0.3$ the area of stability is mostly unchanged as the leg force profile practically shows a linear shape. For $\lambda = 0.5$ the stability region is slightly bent upwards for low angles of attack and low leg stiffness. This is desirable as for a given leg stiffness stable running is possible in a larger range of angles of attack. As one result of our SLIP model based simulation we will use a degressive leg force behavior in our future hardware implementation of *Oncilla robot*.

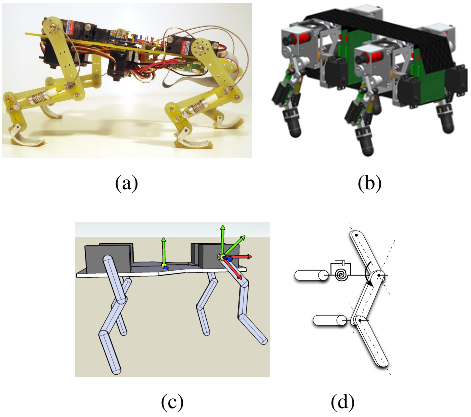

Fig. 1 *(a)* Our previous quadruped robot *Cheetah* (head is to the right)—basis for the robot used in the experiments applying open-loop-CPG. The robot's leg design is three-segmented, and pantographic. Its mid-leg joints are actuated through a cable mechanism. *(b)* Our new *Oncilla robot*, CAD design. New features are optimized gearbox and motor, brushless motor drivers, sensors, and additional compliant units per leg. Knee joints are actuated by an efficient cable mechanism. *(c)* Simulated robot model (simulation environment Webots). *(d)* The panthographic behaviour is hard-coded by a dedicated joint controller. This keeps proximal and distal leg segment parallel at all times. Compliance is introduced by serial elasticity in the proximal knee joint.

3. OPEN-LOOP-CPG CONTROL

To fast and throughout test both the design of hardware and controller we are using a Webots-based, simulated model of *Oncilla robot*. It is controlled with an open-loop-CPG [2], all open CPG parameters are optimized with a PSO-based optimization algorithm. Interesting results indicate a strong dependency of hip amplitude and speed of the robot (Fig. 3). We use the 500 best solutions from each optimization run (repeated several times for the same fixed frequency), plotted are the average robot speed and the robot's hip amplitude. Maximum speed reached is 1 m/s.[1]

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REFERENCES

[1] O. Michel, "Webots 5, fast prototyping and simulation of mobile robots," 2008.

[1]Videos of the corresponding gaits can be found at biorob.epfl.ch/oncilla and biorob.epfl.ch/amarsi

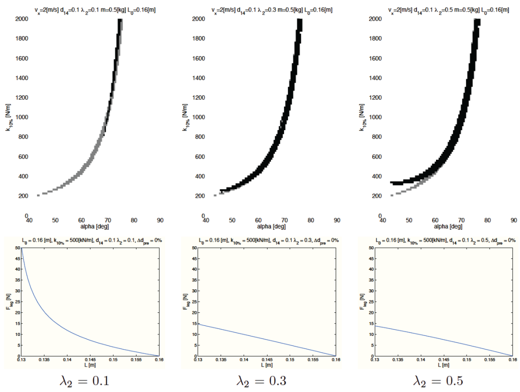

Fig. 2 The first row shows the stability plots for $\lambda = 0.1$, $\lambda = 0.3$ and $\lambda = 0.5$ tested with the apex return map on the SLIP model. The second row shows the corresponding leg force profile (progressive, linear and degressive).

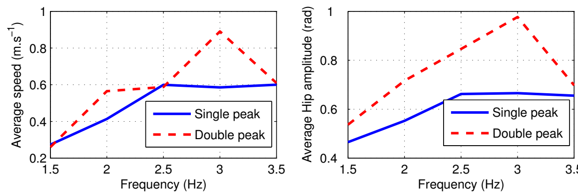

Fig. 3 Amplitude and speed average comparison for two different knee joint control strategies.

[2] S. Rutishauser, A. Sproewitz, L. Righetti, and A. J. Ijspeert, "Passive compliant quadruped robot using central pattern generators for locomotion control," in *2008 Proc BIOROB*, 2008.

[3] J. Halbertsma, "The stride cycle of the cat: the modelling of locomotion by computerized analysis of automatic recordings.," *Acta Physiologica Scandinavica, Supplement*, vol. 521, pp. 1–75, 1983.

[4] H. Witte, J. Biltzinger, R. Hackert, N. Schilling, M. Schmidt, C. Reich, and M. Fischer, "Torque patterns of the limbs of small therian mammals during locomotion on flat ground," *J Exp Biol*, vol. 205, pp. 1339–1353, May 2002.

[5] M. Fischer and R. Blickhan, "The tri-segmented limbs of therian mammals: kinematics, dynamics, and self-stabilization–a review," *Journal of Experimental Zoology. Part A, Comparative Experimental Biology*, vol. 305, pp. 935–952, Nov. 2006.

[6] M. Schmidt and M. Fischer, "Morphological integration in mammalian limb proportions: Dissociation between function and development," *Evolution*, vol. 63, no. 3, pp. 749–766, 2009.

[7] H. Witte, R. Hackert, W. Ilg, J. Biltzinger, N. Schillinger, F. Biedermann, M. Jergas, H. Preuschoft, and M. Fischer, "Quadrupedal mammals as paragons for walking machines," in *Proc AMAM*, pp. TuA–II–2.1 – TuA–II–2.4, 2003.

[8] J. Rummel, F. Iida, J. Smith, and A. Seyfarth, "Enlarging regions of stable running with segmented legs," pp. 367–372, 2008.