

Motion Optimization of a Planar Kangaroo Model

Po-Wei Tseng and Pei-Chun Lin

Abstract—We report on the development of a planar kangaroo model, which has a tail with two degrees of freedom and a compliant and rolling leg. The full body dynamics of the model are investigated, and it serves as an underlying model for the optimization of leg and tail trajectories.

Keywords- motion optimization, kangaroo, model

I. INTRODUCTION

A study on the mechanics of hopping kangaroos suggests that the special physiological and muscular structure that the kangaroo uses for one-foot hopping in the sagittal plane presents a survival advantage [1]. The tendon in the ankle acts as a passive spring, while the tail, with its length close to that of the body, is utilized to adjust the orientation of the body during the hopping motion. On the other hand, the hopping motion, in the style of a “spring-loaded inverted pendulum” (SLIP) is extremely dynamic, and so is challenging to reconstruct in an artificial platform. Penn Jerboa has addressed this by decoupling a robot system into four one-degree-of-freedom sub-systems, and applying controllers separately [2]. In the past, we have reported on the development of a kangaroo robot that utilized two controllers to modulate its motion in the stance and flight phases [3]. The passive dynamic motion of the R-SLIP model [4] is utilized as a reference motion for a robot in the stance phase, without considering the influence of the tail. In contrast, the tail is actively utilized as a mechanism for adjusting the body pitch of the robot in the flight phase. We find that the motion of the robot deviated from the desired trajectories after couple of steps, owing to empirical disturbances and ignorance of full-body dynamics. In this paper, we report on an alternative approach that takes the full-body dynamics of the model into account, and in which the trajectories of the active inputs, such as leg and tail actuations, are derived with optimization methods.

II. TRAJECTORY GENERATION OF THE TAIL AND THE LEG

Figure 1 shows the composition of the planar Kangaroo model, including a rigid body, a compliant leg with mass and pure rolling contact with the ground, and a tail with a movable point mass. The rotational motion of the leg with respect to the body, the swing motion of the tail with respect to the body, and the translational motion of the tail mass with the direction of the tail are regarded as control inputs. The third control input allows the robot to adjust the position of its center of mass and its moment of inertia. The equations of motion for the model were derived with the Lagrangian method. Then, by providing the initial conditions of the model states and the pre-designed trajectories of the control inputs, the dynamic motion of the model could be quantitatively determined.

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Authors are with Department of Mechanical Engineering, National Taiwan University (NTU), No.1 Roosevelt Rd. Sec.4, Taipei 106, Taiwan (Corresponding email: peichunlin@ntu.edu.tw).

Because the model is highly nonlinear and has multiple inputs, it is very challenging to determine the control inputs by using analytical methods. Thus, optimization methods were adopted, with the particle swarm optimization (PSO) and golden section search (GSS) approaches utilized for the model during the flight and stance phases, respectively. PSO is an iterative method that determines the next iteration based on the best solutions for individual particles and their group behavior. By setting multi-objective functions, with Pareto front and weighting functions, the optimized trajectories of the leg and tail could be obtained. It should be noted that although PSO is simple and has a fast convergence speed, special attention should be paid to the boundary and local minimum problems. For the former, a non-restricted method was adopted to adjust the velocities toward search space but not the positions of the particles [5]. To prevent the local minimum problem, an indirect “K means” method was adopted, to determine the degree of uniformity. The GSS is a fixed-step linear searching method utilized in one-dimensional problems. The leg trajectory of the model follows the R-SLIP dynamics, and the tail motion is optimized by the GSS, where a virtual spring is implemented at the joint between the body and the tail.

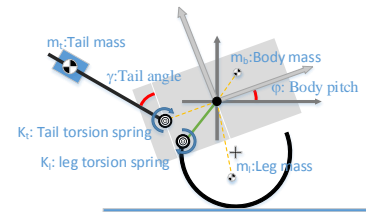


Figure 1 The planar kangaroo model

III. RESULTS AND FUTURE WORKS

We report on the methodology of generating the leg and tail trajectories of a planar kangaroo model based on two optimization methods. Although some optimization limitations still exist, the yielded result is reasonable and feasible for implementation in a robot, because the body pitch of the model can converge to the desired position during flight, and the model can move its tail to the designed position without affecting the body's motion. We are currently in the process of implementing the derived model motion in a robot and evaluating its effectiveness.

REFERENCES

- [1] R. M. Alexander and A. Vernon, "The mechanics of hopping by kangaroos (Macropodidae)," *Journal of Zoology*, vol. 177, pp. 265-303, 1975.
- [2] A. De and D. E. Koditschek, "Parallel Composition of Templates for Tail-Energized Planar Hopping," in *IEEE International Conference on Robotics and Automation (ICRA)*, 2015, pp. 4562-4569.
- [3] G. H. Liu, H. Y. Lin, H. Y. Lin, S. T. Chen, and P. C. Lin, "A Bio-Inspired Hopping Kangaroo Robot with an Active Tail," *Journal of Bionic Engineering*, vol. 11, pp. 541-555, 2014.
- [4] K. J. Huang, C. K. Huang, and P. C. Lin, "A Simple Running Model with Rolling Contact and Its Role as a Template for Dynamic Locomotion on a Hexapod Robot," *Bioinspiration & Biomimetics*, vol. 9, p. 046004 (20pp), 2014.
- [5] S. Xu and Y. Rahmat-Samii, "Boundary Conditions in Particle Swarm Optimization Revisited," *IEEE Transactions on Antennas and Propagation*, vol. 55, pp. 760-765, 2007.