

A HEXAPEDAL JOINTED-LEG MODEL FOR INSECT LOCOMOTION IN THE HORIZONTAL PLANE

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INTRODUCTION

We develop an actuated hexapedal jointed-leg model, with agonist-antagonist pair of Hill-type muscles at each joint, to describe cockroach locomotion in the horizontal plane. This is part of our bigger objective to build a neuromechanical model of insect locomotion including body mechanics, muscles, motoneurons, central pattern generator (CPG), and the sensory system.

Schmitt and Holmes (2000a, 2000b) show that a conservative passively-elastic lateral leg spring (LLS) bipedal model can be stable, supporting the suggestion of Brown and Loeb (2000) that, in rapidly running insects, neural feedback might be partially or wholly replaced by largely mechanical feedback. Our model is based on the principles of LLS, but a little closer to reality and an extension of our work in Kukillaya and Holmes (2007).

MODEL AND ANALYSIS

The insect is modeled as a 2-D object with mass, m , yaw moment of inertia, I , and six legs, their mass being ignored. Each leg, comprising a “thigh” and a “shank” segment, is morphologically similar to the cockroach leg. The “hip” and “knee” joints are actuated by agonist-antagonist pair of Hill-type muscles. With this model, we study insect’s double tripod gaits with 50% duty cycle.

The actuation is purely feedforward in the form of spike-train input to the muscles.

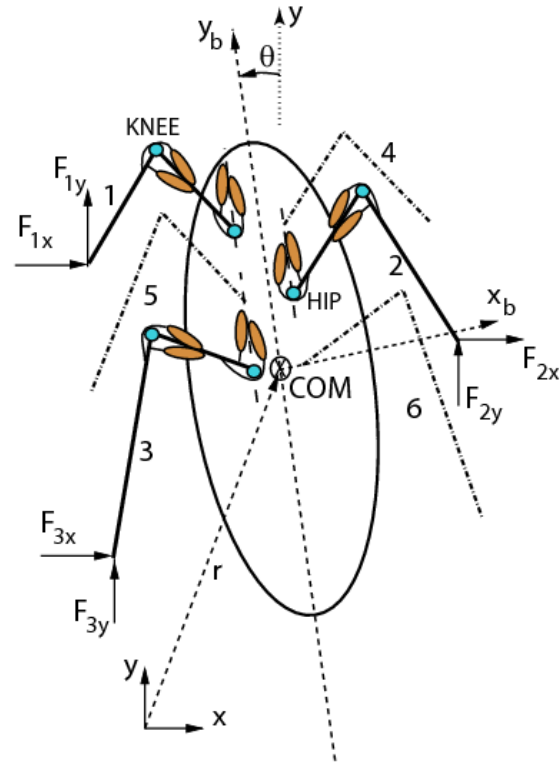


Figure 1: Schematic dorsal view of the insect model. For clarity, the muscles are shown only for the legs in left stance (1-2-3). Right stance corresponds to the 4-5-6 tripod being on the ground. The swing phases are ignored in the present model.

Proprioceptive feedback is implicitly present only as liftoff (LO)/touchdown (TD) signals. LO is purely time based (fixed stride frequency) and at each TD, the feet are kept at prescribed positions with respect to the body. Muscle parameters have been obtained by fitting Hill-type model outputs to experimental data (Ahn and Full (2002), Ahn et al. (2006)).

Time-based sinusoidal approximations of experimental foot-force data provide

necessary joint torques and equivalently the muscle input parameters (inter-spike interval, spike onset time, muscle force scaling). Thus, we obtain a three degree-of-freedom dynamical system driven by feedforward spike-train inputs. We search for periodic gaits of this system and study their stability.

RESULTS

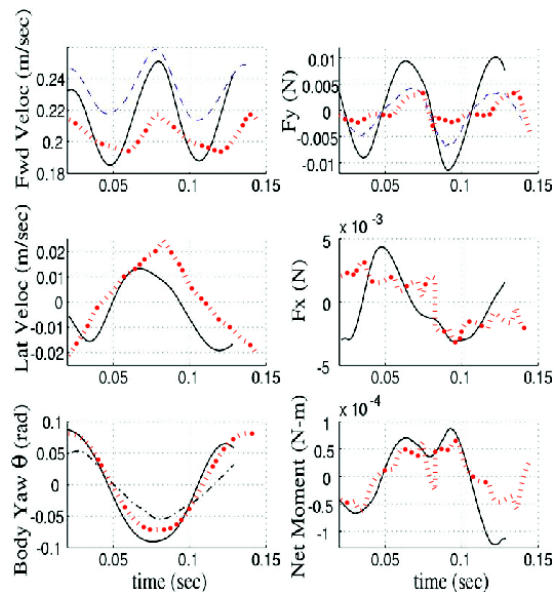


Figure 2: Experimental data (Full et al. (1991), Kram et al. (1997), Full and Tu (1990)) are shown in black; model results are shown as thick dotted red lines.

A stride-to-stride Poincaré map is defined, fixed points of which correspond to periodic gaits of the full system. Stability can be determined by numerically solving for the eigenvalues of the map. Stable and unstable solutions correspond to the insect model running along a straight line and moving in circles, respectively. Figure 2 shows a comparison of the model gait characteristics with experimental data, for a stable periodic gait (running along y axis).

The data is shown for one full stride (left and right stance). It is to be noted that the model results are shown for a different average forward speed ($V_y \approx 0.2$ m/s) and stride frequency than those for the experiment. The model and insect gaits match closely in all the variables.

CONCLUSIONS

The present model with Hill-type muscles exhibits stable periodic gaits which has good comparison with the insect gait. We want to do a complete stability analysis for the model in the insect's typical speed range (0.1-0.6 m/s). Further, we hope to study the robustness of these stable gaits by applying impulsive lateral force perturbations and randomizing the foot touchdowns.

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