Control of Spring-Mass Running Robots

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Abstract

We seek the control strategies that are applicable on legged robots and control them to run in real world as robust and efficient as animals. To achieve this goal, we need to understand the principles of legged locomotion and the control policies that animals use during running. In this study we tried to understand these principles by investigating birds’ running experiments, and hypothesized their possible control policies that are important for real machines. We proposed two types of flight phase control techniques inspired from ground running birds for spring-mass running robots and derived mathematical formulas for the optimum design of the passive elements in these robots. For the control policies, we focused on flight phase because adjusting the leg parameters during the flight is very energy efficient and also the overall behavior of the system is very sensitive to the landing conditions that are determined during the flight phase of running. We first considered the change of the leg angle as the only control parameter during the flight phase. In the proposed control policies, three objective functions i) leg peak force, ii) axial impulse and iii) leg actuator work, all from passive stance phase, were considered to be regulated during running. It turned out that with a simple swing leg policy (constant leg angular acceleration), all the three objective functions can be nearly regulated at the same time, meaning that both goals of damage avoidance and energy efficiency can be fulfilled at once. After that, we investigated the effect of the leg length in addition to the leg angle on the dynamics of the spring-mass running robots. This control policy retains the steady state running by providing the equilibrium gait for each stride. The leg length and leg angle together make it possible for the robot to retain the steady state in the presence of a disturbance while limit the increase of the leg force which if increases may break the leg. In all of the control policies, the robot is purely passive during the stance phase and therefore the dynamics of the system comes from the passive dynamics of the system. Finally, we investigated the effect of the passive dynamics elements on the initiation of running. We derived mathematical formulas that determine the required stiffness and damping for the actuator to achieve the maximum possible performance given the physical limitations of the system.

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