Dynamics Modeling and Control Architecture for Efficient, Manoeuvrable and Robust Monoped Hopping over Rough Terrain

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1 Motivation

Leg dynamics and control have been widely studied using mass-spring systems such as the Spring Loaded Inverted Pendulum (SLIP) model [1]. The SLIP model is commonly accepted as the simplest model that resembles leg dynamics. While simplicity facilitates the understanding of the basic aspects of system behavior, it can result in neglecting some essential factors from control perspective such as leg mass, hip actuation and energy dissipation. Neglecting such aspects increases the gap between simulated results and what can be achieved in reality. Furthermore it makes the transfer of the gained controllers onto robotic hardware difficult. We thus aim at preparing sufficiently detailed mathematical model that can accurately describe the dynamical properties of our monoped hopping robot. We then exploit this detailed knowledge to design control laws which provide a more energy efficient, manoeuvrable and robust behavior in unstructured environment. We validate the proposed method in a challenging scenario where the hopper is expected to pass through rough/sloped terrain while maintaing a desired speed and acting in the vicinity of an energy-optimized gait.

2 State of the Art

Several recent works have concidered extensions on the SLIP model by e.g. adding leg mass [2], energy dissipation and hip actuation [3]. This conceptual model has also been the base for several control approaches such as the successful Raibert robots [4] and also some simulation works such as Ref. [5]. On the other hand there are multi-body rigid dynamics approaches which provide more elaborated modeling of the system [6]. In addition to providing a more accurate model of the robot, the latter allows a more robust, reactive, and compliant control of the robot, thanks to its accurate feedforward compensation term. Reference [7] describes the overall architecture how to use such modeling for floating base systems. However, direct implementation of this architecture for our monoped robot is not possible due to its underactuated mechanism. Examining its controllability condition [8], using orthogonal decomposition method to design projected inverse dynamics control, implementing event-based stabilization over hybrid states and providing speed-regulation controller are the contributions of this work which to our best knowledge have not been combined together for such detailed monoped model.

3 Our approach

We use the tools from [6] to provide a mathematical model which carefully matches with the geometrical and inertial properties of our robotic leg (designed in the scope of European project Locomorph). Leg masses, trunk inertia, simplified actuator dynamics and energy dissipation are taken into account. We use analytical tools [6] to measure cost of transportation (COT) and stability of the gaits. In order for the simulated monoped to perform efficiently, the nominal open-loop gait is extracted with an optimization over COT for a desired speed. Given the fact that the open-loop gait is unstable, we design a control framework to stabilize it. This framework is composed of (*i*) a feedforward block to provide good nominal trajectory following, (*ii*) a feedback controller to suppress perturbations, (*iii*) a trajectory generation block which performs the stabilization over hybrid states and (*iv*) a self-organizing controller which maintains the desired speed. Figure1 shows the control diagram.

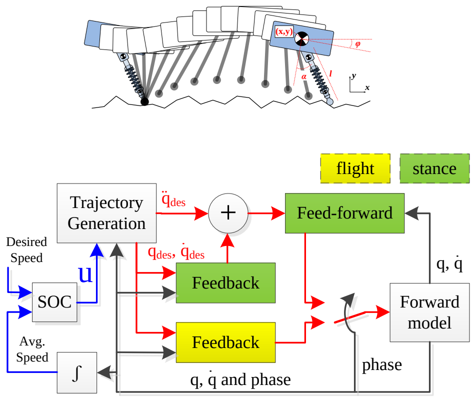

Figure 1: The schematic of the monoped model and control architecture.

4 Results and Discussion

We have evaluated the proposed framework on moderately rough terrains and max ± 20 deg slopes. The experiment results confirm that by combining these intuitive and simple control laws the monoped robot is able to not only successfully handle the rough terrain and positive/negative slopes but also maintain the average forward speed. Thanks to the feedforward prediction, the same performance is achieved with 10 times lower PD gains. Furthermore, the proposed framework allows the robot to perform around the COT optimal working point. We have recently developed the 3D full dynamics of the robot and plan to test the proposed control algorithm on this model as well as the real monoped robot.

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