An Optimization Approach to Controlling Jump Maneuvers for a Quadrupedal Robot

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1 Motivation

Legged locomotion enables humans and animals to traverse difficult terrain with great agility. Their skills to overcome large obstacles are impressive and superior to those of state-of-the-art legged robots. Our motivation is therefore to develop novel control methods for quadrupedal robots to increase their performance in this regard. More precisely, we seek for motor skills for the quadruped robot StarlETH [1] to enable various jump maneuvers. Our aim is to develop a generic framework to create various jumps like a vertical, long or a spin jump.

2 State of the Art

Robot jumping has already been studied intensively for single legged robots [2, 3, 4]. Raibert's seminal work [2] on monopod hoppers with telescopic legs showed that a rather simple set of control laws is applicable to a large set of motions and robots. Control was simplified by the design of the robots as noted by Wong and Orin [5] who analyzed a quadruped standing jump over obstacles in simulation. The design of feedforward contact force profiles enabled their planar quadruped with telescopic legs to jump over ostacles. Manually tuned contact force profiles were also employed by the MIT cheetah [6] to bound over an obstacle. A rather simple bang-bang joint torque controller, but in combination with a smart limb coordination and timing schedule, lead to successful acrobatic maneuvers of the hexapod XRL [7].

Designing more complex motions for various locomotion tasks has been enabled by the development of novel optimization algorithms in recent years. Krasny and Orin [8] applied a Genetic algorithm to find a gallop in combination with a jump for a simulated quadruped. Agrawal and van de Panne [9] used a multi objective optimization framework based on CMA-ES to search for jump controllers for a bipedal character. Optimization methods and learning techniques are useful tools to find complex motions. So far, these methods are, however, not yet applicable to real-time motion planning due to the high computational power needed for these nonlinear, non-smooth and high-dimensional problems (cf. [10]).

Instead, direct policy search has been used in combination with parameterized controllers. A leaping motion for the wheeled quadruped PAW has been first tuned in simulation with a Genetic algorithm and was then successfully executed on the real robot [11]. For the LittleDog quadruped, an algorithm called Policy Gradient with Signed Derivative helped to optimize a "front-leg" jump to quickly climb up large steps [12]. In our previous work, we also applied different black-box optimization algorithms for motion synthesis. For the single legged robot ScarlETH with two joints we employed PI^2 [13] and $ROCK^\star$ [14] for jumping and hopping maneuvers.

3 Own Approach

Our approach to generating jump maneuvers is to employ a model-based state-feedback controller which tracks optimal feedforward motions. The whole-body controller uses a virtual model controller together with a contact force optimization for tracking the desired motion as described in our prior work [15]. The parameterized open-loop motions are optimized with the sampling-based algorithm CMA-ES [16] in simulation and are then directly applied on the real platform. We show that direct policy search can be successfully applied to complex dynamical systems with high-dimensional state and action space, enabling highly dynamic jump maneuvers.

To ensure that the optimized control policies work well also on the hardware platform, an accurate model of the robot is essential. For automatic parameter tuning of dynamic gaits, we could safely neglect the actuator dynamics [17]. However, during a jump, when the actuators operate in the high-performance region, various saturation and friction effects have a large influence on the performance of the system. We therefore use a detailed model of the series-elastic actuators of StarlETH to accurately predict the behavior of the robot during a jump.

4 Current Results

Our approach was successfully tested on the quadruped robot StarlETH[1]. The robot was able to jump up to a height of 0.76 m, which corresponds to 150% of the leg length as shown in figure 1. Furthermore, the robot was able to clear a gap of 0.23 m using a long jump. The method is able to create dynamic motions in full three-dimensional space, which was verified with a spin jump. The robot jumps and turns around its vertical axis up to 43°.

5 Best Possible Outcome

Based on our results, we believe that optimization methods have a large potential to generate complex behaviors and motion skills for a wide variety of legged robots. The proposed method could eventually be used to create a motion library for dynamic maneuvers to enable autonomous locomotion in challenging terrain.

[1] Video https://youtu.be/aEsxLN9CnyE

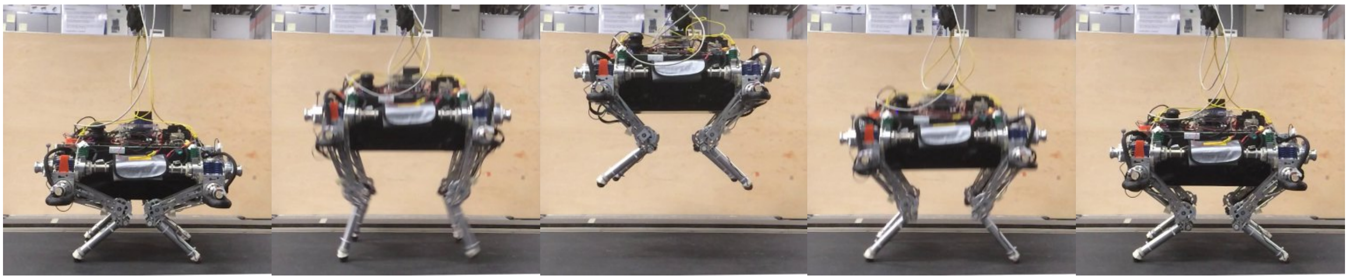

Figure 1: The torque-controllable robot StarlETH performs a vertical jump: initial pose, take-off, apex, landing, end pose.

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