# Controlling Dynamic Gaits for Quadrupedal Robots

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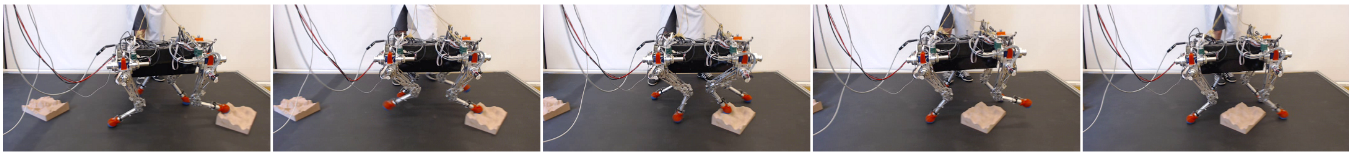

Figure 1: The quadruped StarlETH performs a walking trot while dealing with unperceived obstacles.

## 1 Motivation

Bridging the gap between the skill sets of legged robotic systems and that of real animals is one of the major challenges in the field of robotics. Our long-term goal is to develop and control quadrupedal robots that are able to operate semi-autonomously, i.e. they are only guided by users through high-level velocity commands, such as move forward at 1 m/s, or turn with 0.5 rad/s. To achieve this, the robots should have a large repertoire of gaits and the ability of selecting them based on desired speed, energy efficiency considerations, or the upcoming terrain. At the Autonomous Systems Lab we recently developed StarlETH (Springy Tetrapod with Articulated Robotic Legs), an electrically driven quadruped robot [1]. StarlETH's weight of 23kg and leg length of 0.4m correspond to the dimensions of a medium sized dog, and it uses an actuation scheme based on highly compliant series-elastic actuators that enable torque control. Our aim is to increase StarlETH's repertoire of motions to include faster, more life-like dynamic gaits.

## 2 State of the Art

The problem of controlling quadrupedal locomotion is difficult, as the dynamical systems involved are high-dimensional, nonlinear, non-smooth and under-actuated. Moreover, appropriate control policies need to be robust to unplanned disturbances because the environments legged robots need to operate in are only partially observable. Despite these challenges, a great deal of research aimed at developing and controlling quadrupedal robots has been presented. Statically stable locomotion solutions, for instance, have been studied extensively [2, 3]. While well-suited for slower motions, these methods have not yet been shown to match the agility of real-life animals [4]. Boston Dynamics' BigDog [5] is one of the most recognizable legged robots, and it is capable of an impressive array of locomotion behaviors. The exact details of the employed control algorithms, however, are not publicly available. IIT's HyQ [6], another hydraulically actuated quadruped, was recently shown to trot robustly by employing a virtual model control [7] approach for each leg [8].

The robotic platform we work with is electrically-driven and uses highly-compliant series elastic actuation in order to provide torque control capabilities and increase energy efficiency. Our system therefore allows us to investigate sophisticated torque control methods for legged locomotion [9, 10]. It is our hope that this system will allow us to push forward the state of the art in locomotion control for quadrupedal robots.

## 3 Own Approach

To address the challenge of legged locomotion for compliant quadrupedal robots, we combine different control methodologies. First, a cascading control structure decouples the locomotion control problem from the actuator control problem, as the latter strongly depends on the hardware that is employed. Second, we make use of model-based approaches to control the desired motion of the multi-body system. Third, we exploit domain knowledge, i.e. heuristics, such as pre-defined foot-fall patterns, and templates to address the problem of motion generation. To this end we build on the framework described by Coros et al. [11]. The control scheme combines several simple building blocks. An inverted pendulum model computes desired foot fall locations, PD controllers regulate the motions of the legs and virtual forces are used to continuously modulate the position and orientation of the main body. We improved the process of distributing virtual forces to the stance legs and we implemented a gait transition method to smoothly change the gait while walking. Lastly, we apply optimization and learning techniques to find optimal parameter values for our control policies.

## 4 Current Results

We implemented controllers for a static walk, a walking trot, and a running trot, and show that smooth transitions between them can be performed. Using this control strategy, StarlETH is able to trot unassisted in 3D space with speeds of up to 0.7m/s, it can dynamically navigate over unperceived 5-cm high obstacles as shown in Figure 1, and it can recover from significant external pushes [10].

## 5 Best Possible Outcome

Our main contribution is the development of a flexible locomotion control framework that we have applied both in simulation and on a quadrupedal robot. In the future, we aim to extend the repertoire of gaits from walk and trot to bound and gallop. We want to develop automatic methods of optimally selecting appropriate gaits based on the desired speed, energy considerations or the environment in which the robots operate. We therefore need to create control policies that allow transitions between different gaits. To increase agility, we also plan to investigate methods that allow the robot to execute maneuvers like fast accelerations and decelerations, sidestepping, and turning sharply. Another main objective of our work is to create control policies that can be employed in arbitrary environments. Consequently, we plan to also further investigate foot placement strategies as well as reactive control methods for balance recovery.

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