

Ontario Graduate Scholarship: Plan of Study

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Background

When a gymnast is performing a swing-up routine on a bar, they do not kick their feet at specified time intervals. Rather, a more natural human motion is to smoothly swing their legs based on their current speed and position [1]. In doing so, they are able to generate enough momentum to perform backflips on the bar. When controlling mechanical systems, standard practice is to have a robot's actuators track a function of time. Much like the gymnast, it is often more natural to track a function of the robot's current speed and position. The recent techniques of virtual constraints offer this ability and produce realistic, biologically plausible motion.

Mechanical systems can be constrained in two ways. Holonomic constraints restrict position (for instance, car tires remain a fixed distance apart), while nonholonomic constraints restrict velocities (such as how car tires cannot slide sideways). Previous research has shown that one can enforce holonomic constraints through a robot's actuators, using the method of "virtual holonomic constraints" (VHCs) [2]. VHCs have been used to control walking robots [3], autonomous bicycles [4], gymnastics robots [5], and snake robots [6] among others. These VHCs are a special case of virtual nonholonomic constraints (VNHCs); in my master's thesis [7] I developed a general theory for enforcing VNHCs and designed one which injects energy into the gymnastics robot created by Wang [5], thereby enabling it to perform backflips on a bar.

Proposal

Mohammadi *et.al.* [8] showed that a single VHC can result in several motion patterns (known as "orbits"), from which one specific motion pattern can be chosen if the robot is initialized with a configuration that is "close enough" to it. However, their method does not work for all starting configurations of the robot. We propose to extend this work by investigating a method for transitioning between VHCs and VNHCs.

VNHCs have been studied with applications to human-robot cooperation [9] and walking robots [10]. Horn *et.al.* [11] have also examined properties of VNHCs for general mechanical systems and applied their results to stabilizing a chosen gait on walking robots. Our approach is novel since we assume one has already stabilized a VNHC, and will develop techniques to transition to a different VNHC while maintaining pre-specified safety constraints. Doing so should allow one to start at any configuration and chain together VNHCs to bring the robot "close enough" to stabilize a desired orbit.

First we will study mathematical conditions under which one can transition between two VNHCs. These conditions will allow us to create a control algorithm to switch between motion patterns. After completing this mathematical formulation, we will test the theory on a gymnastics robot by designing a gymnastics routine which is performed by transitioning between several different VNHCs.

Finally, the advancement in mathematics from this research will enable improvements to control of other robotic systems. The ability to transition between complex constraints will allow for more natural expressive motion in many autonomous systems and may become a standard technique for controlling biologically inspired robots.

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