Virtual Constraints Paradigm for Robotic Locomotion Control

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Background. Designing highly mobile biologically inspired legged, winged, and limbless robots has advanced considerably in the past decade. Developing motion control algorithms for these robotic systems, however, is mainly carried out using ad-hoc techniques resulting in motions that are far less agile and efficient than the biological species that have inspired the robot morphology. A recent design paradigm, which has been originally introduced for biped robot agile and efficient control [1], is based on controlling robots using virtual constraints (VC). Virtual constraints are relations among the biped generalized coordinates encoding stable walking gaits that can be re-programmed on-the-fly and are enforced via feedback (see Figure 1). Under virtual constraints, bipeds are capable of achieving stable motions over a wide variety of terrain profiles [1]. MABLE, which is the world’s fastest planar biped with knees, employs virtual constraint-based algorithms in its motion control system [2]. This methodology has recently been applied to control of powered prosthetic legs for amputation patients [3], [4].

Objective. Given the virtual constraints paradigm success in control of biped robots, we would like to investigate whether this methodology can be employed to induce complex behaviors on underactuated mechanical systems such as bioinspired crawling and swimming robots. Our ultimate goal is to develop an overarching virtual constraint-based algorithm design methodology for various modes of robotic locomotion [5]. As one of the initial steps in this endeavor, we have extended this framework by making the geometry of the virtual constraints dynamic [5], [6], [7], [8].

Methodology. The novel concept of dynamic virtual constraints has enabled us to solve the complex maneuvering control of underactuated mechanical systems such as the pendubot [5]. We have also been able to solve the complex problem of planar snake robot locomotion control by using this concept [6], [7], [8]. Similar to bipeds, designing control algorithms for snake robots using traditional techniques is extremely challenging because these robotic mechanisms are hyper-redundant, i.e., they have a very large number of degrees-of-freedom, and underactuated, i.e., they have less control inputs than the number of degrees-of-freedom. The agility and performance of the resulting control algorithms have recently been verified using experiments on Mamba, an underwater snake robot prototype built at the Norwegian University of Science and Technology (NTNU) [9].

Results. We have been able to extend the virtual constraint-based control methodology used in bipeds to other classes of underactuated mechanical systems including bioinspired crawling and swimming robots. We believe that the VC paradigm has the potential to be employed as a unifying motion control algorithm design framework for numerous bioinspired robotic problems.

References


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