Concerted control approach with leg force as a conductor

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Summary

In human locomotion, the complex structure of body is controlled such that conceptual models can describe the significant features. This suggests that the interplay of the complex control and musculoskeletal systems projects into a low dimensional space to perform different movements. Such simplification can involve splitting the task into different modular control subproblems (locomotor subfunctions) that can be solved individually. How locomotor subfunctions could be coordinated to generate repeatable and robust motor commands? Establishing internal sensor-motor mappings between different muscles (actuators in robots) similar to reflex-based control, is considered as a novel approach for design and control of assistive devices such as exosuits and exoskeletons. We suggest utilizing the leg force feedback as interplay among environment, body mechanics, and sensory control to synchronize the decoupled subfunctions. We evaluated this approach in push recovery, attenuating ground drop perturbations and by investigating its sensitivity to the reflex gain as the control parameter.

Introduction

A great progress to simplify understanding of locomotion dynamics and control was made by introducing simple models, coined "templates", able to represent the overall dynamics of animal/human gaits, e.g. the spring-loaded inverted pendulum (SLIP) model. Inspired from template models explaining biological locomotor systems and Raibert's pioneering legged robots, locomotion can be realized by basic subfunctions: (i) stance leg function, (ii) leg swinging and (iii) balancing. Combinations of these three subfunctions can generate different gaits with diverse properties. Using the template models, we investigate how locomotor subfunctions contribute to stabilize different gaits in different conditions. We showed that such basic analyses on human locomotion using conceptual models could result in developing new methods in design and control of legged systems such as biped robots and assistive devices.

Approach: Concerted control

An appropriate body mechanical design of the legged locomotor system is essential for an efficient and robust motor control. In order to complement the role of the body mechanics, we investigated a simple bioinspired approach to synchronize different locomotor subfunctions. The key idea is to use unique sensory information to coordinate motor controllers, involved in a locomotion task. If the contributing elements (e.g., motorneurons) use the same feedback signal (here, leg force), they can be implicitly synchronized, similar to an orchestra in which the musicians follow the conductor's rhythm. To some extent, the HZD (hybrid zero dynamics) control approach [1] can be interpreted based on a similar idea, in which virtual constraints are designed by defining desired joint trajectories as functions of a unique leading variable (e.g., the leg angle). However, in HZD, the basic idea is shaping kinematic constraints that can be supported by stability analyses focusing on the concept of feedback linearization. Instead, here, we benefit from sensor motor map concept inspired from biological locomotor systems [2]. Such a feedback-based coordination supports that inter-joint and task-specific synchronization through simple reflex pathways is possible. This outerloop feedback circuitry can be interpreted as an extension of the sensor motor map concept [2] to a higher level of control that can be called subfunctions coordinator.

Results and Discussion

Recently, we started using this framework of locomotor subfunction control in robotic systems such as exoskeletons. Here, the minimal required infrastructure (on hardware and control level side) covering an effective intervention throughout a wide range of motion targets is of particular interest. In [3], the implementation of the force modulated compliant hip (FMCH) method on the LOPES II exoskeleton resulted in reduced metabolic costs during walking compared to the transparent control. Simulation studies implementing the proposed method using biarticular actuation showed even higher metabolic reductions (up to 13 percent) benefiting from mechanical properties of two-joint actuators in walking assisted by an exosuit [4]. In [5] we showed that leg force feedback can improve robustness of hopping by synchronizing stance and balance subfunctions using concerted control concept. These studies highlight the potential of the novel concerted control concept for future bipedal robots and assistive technologies for different gaits. Such a parsimony bioinspired model-based control concept could simplify controlling assistive devices such as exoskeletons and prostheses.

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