Fitting Task Specific Elastic Potential for Robotic Legs

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I. Introduction

It is a common understanding that efficient legged locomotion requires energy to be stored and released in a cyclic manner. Equipping mechanical leg systems with springs provides this functionality and forms an oscillatory system. It is a design goal to fit this oscillatory behavior to the locomotion task, which is only in few special cases realizable in an exact manner [1]. Abate et al. present a concept of exploiting some kind of mechanical gearing to map a certain stiffness into task space [2]. In contrast, our concept aims to design an elastic potential supporting the whole task execution in an optimal way. Additionally, our concept can also be applied to systems with kinematic redundancies, which cannot be addressed by pure mapping approaches. Limitations of the actuation dynamics caused by low impedance actuation [3], need only be accepted for the task degrees of freedom (DoF). Being only marginally involved during task execution, nullspace DoF allow for high impedance actuation. This enhances the versatility of the system.

This work presents an approach that can:

- Relax the actuator requirement during nominal task execution, by an optimal fit of the elastic properties.
- Tune the intrinsic oscillatory behavior to obtain a behavior similar to the task, by adapting the potential.
- Enhance the disturbance rejection capability, by allowing higher torque bandwidth actuation for certain degrees of freedom.
- Provide an intuitive interpretation of the effect of particular elastic elements in the design.
- Be employed on every cyclic task of articulated robots.

II. Concept

Our goal is to design an elastic potential, that generates torques and forces , as similar as possible to the total task forces while moving along the intended task trajectory. By doing so we gain the work done by physical elastic springs and thus lower the work necessary done by the actuators.

We assume the cyclic task to be a one dimensional curve in joint space. Under some conditions, this allows to identify relationships of the motions of each joint and its predecessor along the kinematic chain. Approximating these relative motions by linear regression we generate a similar motion based on a chain of fixed ratio biarticular couplings. Adding an actuator on each of those couplings spans our approximated nullspace. In the same manner the loads in the joints can be treated, distributing the forces of one single elastic potential over all involved joints.

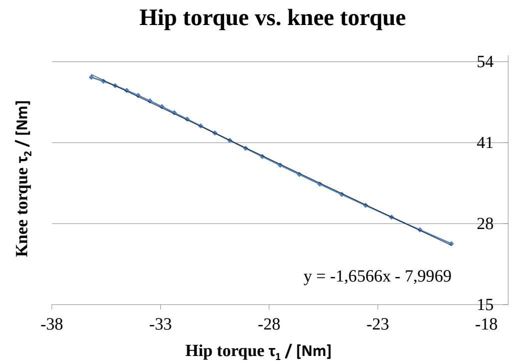

Fig. 1: Fit of the task spring coupling ratio of -1.66:1 from the knee torque τ_2 over hip torque τ_1 plot.

III. Algorithm

The process can be summarized into four steps:

1) Prepare and examine the input data from physical or simulation experiments regarding periodicity and uniformity.
2) Fit displacement variables to generate forces along the task trajectory from the analysis of relative torque trajectories.
3) Generate displacement domains orthogonal to the task directions to stabilize the system pose based on the linear regression fit of relative displacement trajectories.
4) Optimize the stiffness parameters for the task execution.

Figure 1 shows one of the fits, done in step 2. This fit derives the torque ratio of 1.66 between hip and knee task forces for a squat motion on C-Runner.

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme with the grant agreement No 819358, NatDyReL.

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