Optimal Control for Robotic Prosthetics with Interaction Primitives

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I. Introduction

Many prosthetic solutions have been proposed to accommodate those with amputations including powered active devices. Active devices usually target building a state based controller to deliver torque, impedance, or position commands derived from sensor observations. However, selection of control parameters is not well-defined since its influence on biomechanical quantities such as joint loading (e.g., knee contact forces) are not well-understood in all scenarios. Since even small changes in how an amputee walks can have large repercussions such as: musculoskeletal diseases due to increased joint load, decreased walking stability, and increased metabolic cost. [1]

We therefore propose generating a probabilistic model of joint loading with respect to kinematics, kinetics, and control parameters, then using this model to provide optimized control based on task and desired joint loading. We start with a machine learning method called interaction primitives(IP) which is known for creating robust and accurate models of human interactions with prosthetics [2]. Using data augmentation methods we add unobservable biomechanical data which we can then estimate in real-time. Lastly we integrate the optimal predictions into a Model Predictive Control(MPC) framework to account for biomechanical ramifications of control on the human body. **We show that interaction primitives are easily integrated into a Model Predictive Control framework which allows us to optimize control in regards to estimated biomechanical variables.**

II. Method

Our approach focuses on pairing MPC [3] with probabilistic modeling and inference from Interaction Primitives, with the goal of generating optimal control actions based on future state predictions from the learned model of a human robot system. In contrast to previous MPC approaches, we employ a probabilistic model of the system, namely IP, which inherently contains a model of future states. Therefore, we can directly apply formulate the learned model into an MPC problem without the necessity of sampling into future states.

This Method first requires data, collected from a human action, which represents typical variations in the activity, in our case a vertical jump. We augment the data with biomechanical variables from the subject, calculated via tools such as inverse dynamics on a biomechanical model, as well as control signals such a subject joint angles. With the full data set we train the predictive model, which extracts and efficiently represents, the correlations in the data both temporally and spatially. Given a new observation, the predictive model will then generate optimal estimates of the observations, latent biomechanical variables, as well as control signals.

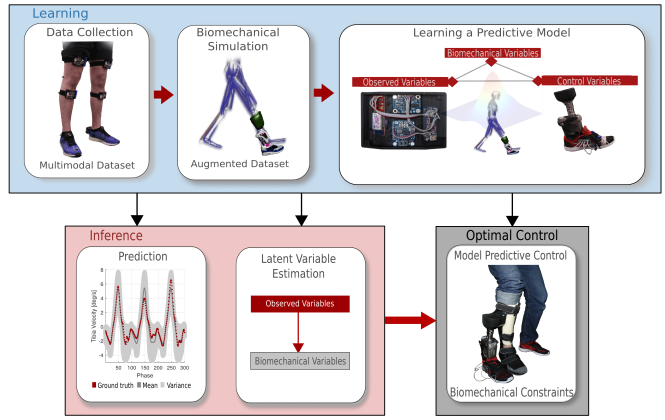

Fig. 1. Overview of approach: Collected data is augmented with biomechanical information and used to learn a probabilistic model, called an Interaction Primitive. This model generates predictions within an MPC framework to produce optimal controls with Biomechanical Constraints.

While the predicted control signal is an optimal estimate in the sense that it contains the smallest error given the trained data, noise characteristics, and new observation, it is not necessarily the best or healthiest control signal for the subject. Instead the probabilistic model can again be used, this time in a cost function to provide a control signal which minimizes biomechanical features such as knee force. In this way MPC with IP can provide a control signal without an analytical formulation of the dynamics.

III. Results and Discussion

This method was used to learn the dynamics for multiple healthy subjects in a vertical jumping task and tested by fitting them with a carbon fiber ankle bypass and a robotic prosthetic ankle. We show that we are able to both accurately predict sensor values, joint forces, and control signals; as well as generate optimal control actions which minimize or maximize joint forces or moments. We further examined experimentally the effects of different cost functions and their efficacy during both take-off and landing of vertical jumps. While this process was tested on vertical jumping only, we expect positive results when tested on other dynamic actions.

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References

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