Learning Musculoskeletal Dynamics with Non-Parametric Models

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***Abstract*— Gait control of bipeds has been a key challenge in robot locomotion for decades. A key component toward controller design is a good model of the robot and its interactions with the environment. For systems with highly compliant and complex actuation, however, deriving the models for the essential system components is quite tedious. In this paper, we propose to learn non-parametric models for a human inspired musculoskeletal biped, whose nonlinear actuation dynamics and passive tendon elasticities make modeling very challenging. We present first promising results that hint at the usefulness of data-driven modeling approaches in the context of legged robots.**

I. Introduction

Gait control of bipeds has been a key challenge in robot locomotion for decades. Finding good controller parametrization typically requires a sufficiently detailed multi-body system dynamics model of the robot at hand. However, the development of a such model is much more challenging for elastic musculoskeletal systems than for conventional robots with rigid actuation and requires a proper validation prior to its use.

In the following, we propose to learn data-driven non-parametric models for the human inspired musculoskeletal BioBiped1, shown in Fig. 1. It stands out by its highly compliant active and passive actuation comprised of nine mono- and biarticular human-like muscle-tendon structures. These structures represent the muscle groups that are essential during human locomotion [1]. Each leg is three-segmented and has in the hip, knee, and ankle joints a degree of freedom along the pitch axis. Hip extension and flexion are actively supported by a linear bidirectional actuator. In the knee and ankle joint, only the function of the extensor is actuated by a series elastic, electrically driven tendon with nonlinear transmission dynamics. In addition to the antagonist functions, the roles of three biarticular muscles coupling hip/knee and knee/ankle joints are implemented as passive elastic tendon structures.

II. Model Learning

For learning a model of the BioBiped in Fig. 1, we use non-parametric Gaussian processes (GPs). In the case of the BioBiped1, the non-parametric property of the GP is convenient, since it is not necessary to explicitly specify the model parameters to describe the rigid body, compliant actuation, and impact dynamics of the system. Instead, the GP infers a posterior over models directly from data.

We obtained 9 s of data from a hopping gait of the real robot at a frequency of 100 Hz. To train the GP model, we randomly selected 200 state-control pairs from the data set as training inputs. The training targets were the corresponding successor states 10 ms later. The GP was trained by means of evidence maximization. Fig. 2 shows the quality of the learned model for two state dimensions: the normal ground reaction forces, which were particularly difficult to predict, and the angle of the left knee. For both cases, the quality of the learned model was good since the true states (red line) were within the 95% confidence bounds of the predictions (blue, shaded). The quality of the learned model for the real BioBiped1 confirms the quality of the data-driven models learned for a simulated biped [2].

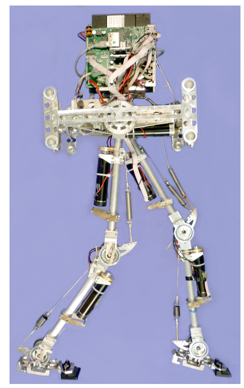

Fig. 1. The BioBiped1 has highly compliant active and passive actuation comprised of nine human-like muscle-tendon structures.

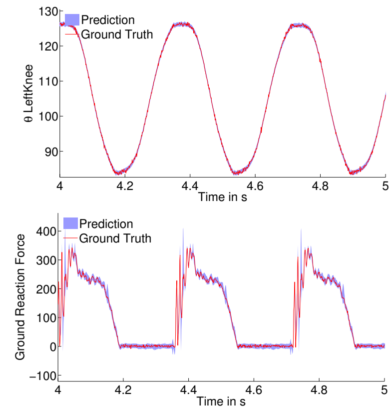

Fig. 2. Model learning results. Real data is shown in red, the 95% confidence bounds of the learned model's predictions are represented by the shaded areas. Even with only 200 training data points, complex relationships, such as the ground reaction forces, are modeled well.

III. Conclusion

We have presented a data-driven approach to learning musculoskeletal dynamics for the BioBiped1, a bio-inspired robot with compliant actuation. We focused on learning models for a hopping gait of the real biped. In future, we will compare the data-driven with an analytical model and assess their respective benefits. Moreover, we will use these models for gait optimization w.r.t. energy efficiency and robustness.

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References

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