Supplement for: From Adaptive Locomotion to Predictive Action Selection – Cognitive Control for a Six-Legged Walker

Authors

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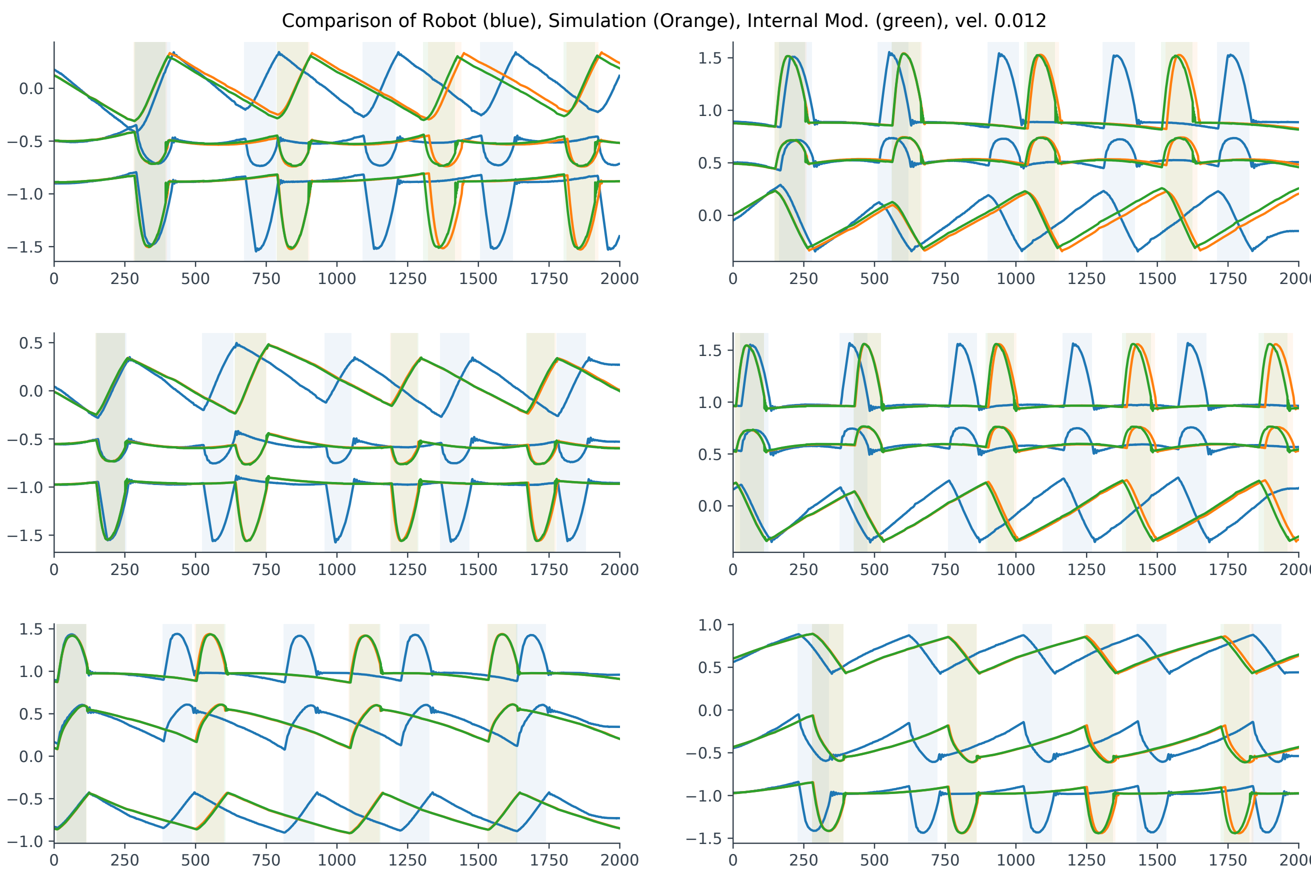
Comparison Prediction of Internal Simulation with Real Behavior

In our architecture, an internal model realized as a recurrent neural network is used to internally simulate and predict actions and behavioral consequences. In an internal simulation, behavior is rolled out for multiple timesteps (in our case a couple of seconds in order to determine if the selected behavior solves the problem at hand or endangers stability of walking). The internal body model is quite simple and only consists of a couple of neurons. Therefore, it is important to assess how well this simple model is able to predict and match real behavior of the robot. In this evaluation, we used original movement data from the real robot (walking on flat terrain) and compare this data with simulated movements: On the one hand, we compare these data with the behavior predicted by the internal body model (the RNN). On the other hand, we use our control model in a dynamical simulation environment and apply the motor commands in this simulated setting. Therefore, we end up with three different sets of data. All started from exactly the same state as recorded in the real robot. But after initialization, we ran the system using feedback from the chosen model in order to update the state. The different models were not simply run using prerecorded motor commands from the original robot in an open loop fashion. Instead, the models were used in a closed loop fashion. The Walknet system controlled the motor commands based on the feedback from the specific model used — this means that for using the internal model in the internal simulation case, the updated state was the one received from the internal model (see Fig. S6).

a)



b)

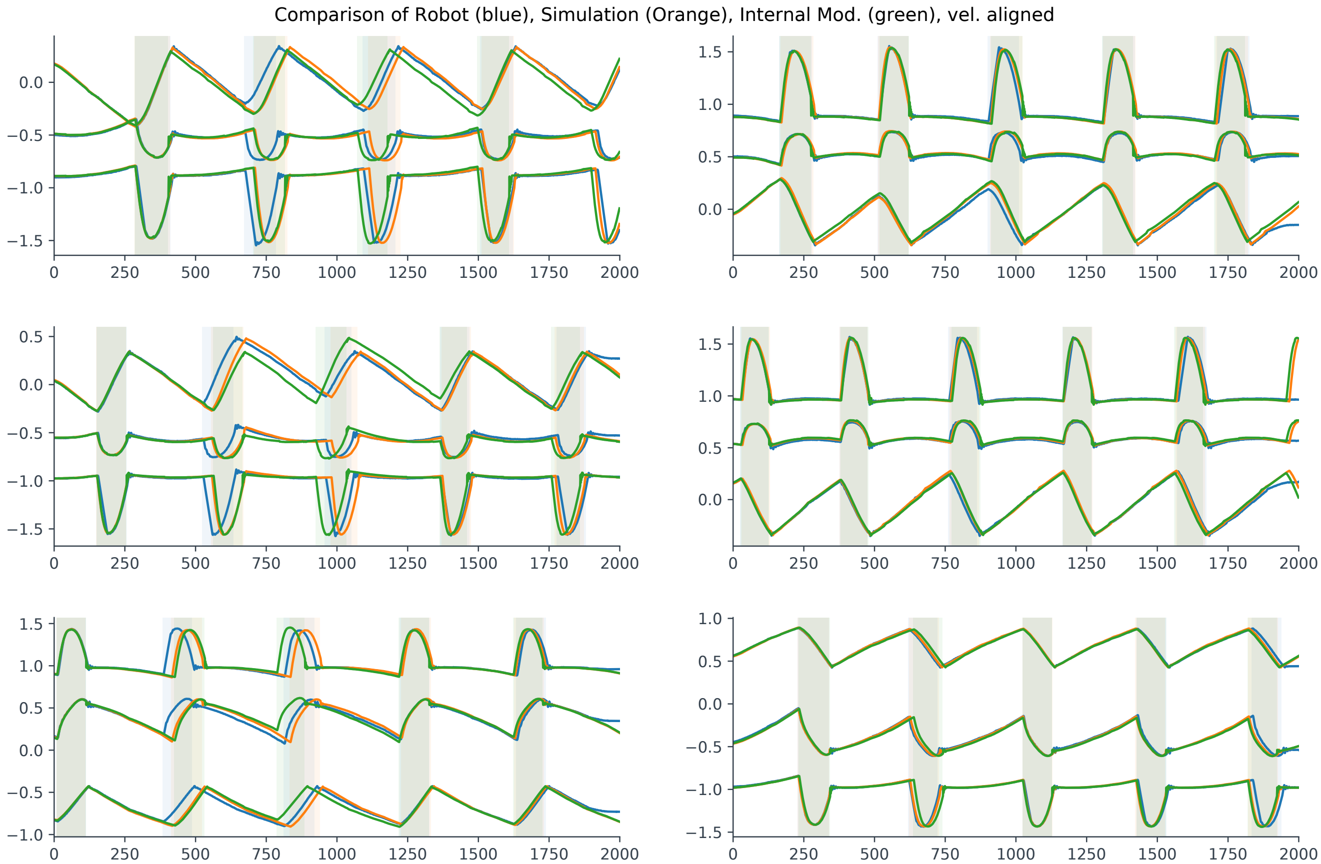


Fig. S6: Comparison of behavior on the real robot (blue), in dynamic simulation (orange), and in internal simulation (green). Internal simulation is used for prediction of behavior using the recurrent neural network-based body model. The two figures (a, b) show that the control system behaves qualitatively quite comparable as the emergent behavior is characterized by the same walking pattern. In a) we observe as a large difference that the stance movement on the real robot is carried out faster. In b) the stance velocities are therefore aligned, which shows that the resulting behaviors are close to identical and that, after small deviations, the system converges to the same stable behavior. Left column: left legs, right column: right legs. From top to bottom: front legs, middle legs, hind legs.

As the controller was using the prediction as an input, one might expect that errors and differences are rapidly accumulating over time. However, we find that there is only one huge difference between real robot and both simulations (Fig. S6 a)): The stepping frequency on the real robot (shown in blue) was much larger compared to internal simulation (shown in green) or when using a dynamic simulator (orange). A possible explanation is that the feet of the robot were slipping which is difficult to simulate and which appears much more pronounced on the real robot. When the real robot moves his feet backwards during stance movement, part of the force leads to slipping of the feet which results in faster motion of the leg and shorter (in duration) stance phases. For a better comparison and to compensate this effect, we aligned the stance velocity and run the controller again in internal simulation and dynamic simulation (Fig. S6 b)). In this case, we see only minor deviations between internal simulation and both, real robot as well as dynamical simulation. This means that the walking patterns look astonishingly similar, which underlines that a stable pattern emerges from the interaction of the decentralized controllers. The coordination appears quite robust to disturbances (which are unavoidable on a real robot due to sensory and motor noise). Only on the left side, we can observe a deviation during the second step. It propagates from the hind left leg through the middle and front left leg, but, importantly, through coordination with the right side, the overall emergent behavior is forced back to the stable locomotion pattern over the next two steps. To summarize, while there are small differences between robot and internal model, on a qualitative level these behave quite similar supporting that the internal model appears suitable for behavioral predictions.