Toward a robust control of bipedal walking from human demonstration

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Despite a vast literature on legged locomotion, it is not fully understood how human walking is controlled or how robots can be made to achieve humanlike walking. Our broad aims are (a) to test biological models of limb mechanics and control, and (b) to use these models to develop robust control schemes for artificial limbs, orthotic braces, and legged robots. In addition to technological innovation, this approach may lead to a better understanding of the neuromechanics that determine gait performance. In this paper, we report progress toward our goal of a control system for bipedal walking that learns from human demonstration.

The control described here is derived from motion and force-plate data captured at a gait laboratory. We have developed a 3-D, 12-degree-of-freedom model representing the legs and lower torso of a human. The joints and links of this model closely match those of the captured motion. Thus, the motion data can be applied to the model to obtain forces via inverse dynamics. The model can also be run in forward-dynamics mode to test the control, which is described in terms of virtual model components [1]. These components provide a high-level means of translating desired forces on parts of the model into commanded joint torques. It has been shown that a simple configuration of such components can achieve 2-D walking in a bipedal robot [2]. Here, possible configurations are evaluated for their biological plausibility and their ability to produce humanlike walking. For example, the model's legs can be made to act as compliant spokes of a spinning wheel. In this scheme, which has similarities to those used recently for quadruped animal simulations [3] and a hexapod robot [4], the important control parameters are the mechanical impedances, tangential velocities, and swing periods of the legs. The virtual model components have parameters that affect their control behavior and need to be adjusted. The motion data are analyzed to provide biological estimates of these parameters. Analyses include center-of-mass trajectory and effective lengths and velocities of the stance and swing legs. The resulting model predictions are tested with force-plate data from subjects walking at three different speeds, and robustness of the model with respect to disturbances is evaluated. For tuning of model parameters, a supervised learning architecture is proposed. Inverse virtual components can convert joint torques from the motion capture into force specifications that correspond to a reduced-order model. Supervised learning is used to learn the characteristics of this reduced-order model and thereby to achieve a form of learning from demonstration [5], where the demonstration consists of the captured motion data.

The significance of this work is twofold. First, the model provides a framework for testing the role of specific control mechanisms in the generation of walking behaviors. Second, a robust control based on demonstration will be useful for implementing biologically realistic robots and assistive technologies. Future work includes testing the control system on existing hardware (e.g., a 3-D humanoid walking robot), and adapting the control for powered orthotic braces that compensate for gait pathologies.

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References

[1] J. Pratt, A. Torres, P. Dilworth, and G. Pratt. Virtual actuator control. In *Proceedings of the IEEE International Conference on Intelligent Robots and Systems*, pp. 1219-1226, 1996.

[2] J. Pratt, P. Dilworth, and G. Pratt. Virtual model control of a bipedal walking robot. In *Proceedings of the IEEE International Conference on Robotics and Automation*, pp.193-198, 1997.

[3] H.M. Herr and T.A. McMahon. A trotting horse model. *International Journal of Robotics Research* 19: 566-581, 2000.

[4] U. Saranli, M. Buehler, and D.E. Koditschek. Design, modeling, and preliminary control of a compliant hexapod robot. In *Proceedings of the IEEE International Conference on Robotics and Automation*, pp. 2589-2596, 2000.

[5] S. Schaal. Is imitation learning the route to humanoid robots? *Trends in Cognitive Sciences* 3: 233-242, 1999.