Learning Bipedal Locomotion by Demonstration

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The Problem: To develop a bipedal locomotion control system, based on learning by demonstration, that achieves robust, realistic-looking gaits.

Motivation: Human-like, robust bipedal locomotion is important in a number of applications. Much of the terrain in the world is not accessible by wheeled robots, but can be easily traversed by humans. If robots could be given human-like walking capabilities, they would be able to traverse such terrain the way humans do. Computer animations could benefit from simulated human models that walk and run in a realistic way. Such a control system could be used in prosthetics for patients with neuro-muscular walking-related handicaps.

Previous Work: Many approaches have been used to control bipedal walking systems [1, 2, 3]. Collectively, these systems (simulated and real), have walked on slopes, over steps, and have achieved running. However, it is fair to say that the field is still a long way from robots that can walk as well as humans can. Given that biological evolution has provided a highly optimized locomotion mechanism, it makes sense to investigate whether a control system that learns from human walking demonstrations can achieve improved robotic locomotion.

In recent years, there has been a great deal of research in the area of learning by demonstration [5, 6]. This has been fueled by the exponential increase in computing power, and by recent developments in machine learning. Much of this work has focused on robot manipulator control. There is thus an opportunity to apply these new techniques to the more difficult problem of robot bipedal locomotion.

Approach: To support this effort, walking motion capture data is being collected. The data covers a variety of gaits and walking styles, including those of patients with neuro-muscular handicaps that interfere, in various ways, with normal walking.

Deriving automatic locomotion control systems from this data will require experimentation with, and combination of, a number of advanced technologies, including learning algorithms and advanced, high-performance dynamic simulations. The demanding requirements of this application will require innovation in both of these areas. Once a better understanding of control laws has been achieved, it will be possible to estimate walking states based on a limited set of sensor inputs. Since the motion capture data will include trajectories from patients with walking handicaps, it will be possible to build observers that estimate the state of the patient and anticipate intent. This will allow for development of orthotic devices that augment the action of weakened muscles or neuro-muscular systems.

Difficulty: Control of an articulated system of links is an inherently difficult control problem. The state space is huge, the dynamics are highly non-linear, and there are multiple inputs and outputs. Robot bipedal locomotion adds an extra set of difficulties beyond those encountered with a robot manipulator. The contact of the robot's foot with the ground forms a somewhat unactuated joint; there is a limit to the torque that can be exerted by this joint. This limit is dictated by the area of the foot in contact with the ground. Further, when the robot is running, there are times where neither foot is on the ground and the system goes ballistic. Thus, there is a need to balance and maintain dynamic stability.

Human-realistic walking has not been achieved, not even in simulations that realistically model link dynamics and interaction with the ground. One reason is that it requires models that more closely resemble humans. The additional complexity greatly increases the complexity of the control problem. The state space becomes huge, and the possible control decisions are essentially infinite. For this reason, it is useful to seek guidance from an expert source: the motion trajectories for human walking. These can be used to greatly reduce the search space of interest. In addition, movement primitives can be extracted so that the control problem is transformed from one of searching the (huge) state space of the robot, to searching the much smaller space of combinations of movement primitives.

Estimation of walking state for the purpose of controlling an orthotic device is also a difficult problem. The minimal set of required sensor inputs is unknown, and is likely to vary depending on the type of handicap. Also, the control system will have to calibrate itself automatically to conform to the variations in size and behavior of the users.

Impact: Development of control models that result in human-like locomotion would be of great benefit to any robot locomotion effort. The control models developed in this project could be adapted to a large variety of robots, allowing them to more closely approximate the capabilities of ordinary humans. The use of such models for orthotics and exoskeletons would allow people with handicaps to better navigate terrain the way non-handicapped people do. The use of such models in computer games would provide a more realistic experience for the user.

Future Work: The techniques developed as part of this project could be extended to analyze more complex dynamic motions such as the ones used in sports or dance. This would allow for improving the capabilities, not just of robots, but potentially, of humans as well. For example, if the control laws of a human expert at such an activity (a champion golfer or professional dance competitor for example) could be captured, they could be used to train less expert individuals and improve their performance.

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Figure 1:

Research Support: This work is supported by a philanthropic gift from Phil Carvey, acc. 2733027.

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