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Learning Capture Points for Bipedal Push Recovery

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Researchers at IHMC and Honda Research Institute are developing techniques for Learning Capture Points for Bipedal Push Recovery. A Capture Point is a point on the ground where a biped can step to in order to stop. Humans are very adept at stepping to Capture Points, while most bipedal robots cannot recover from significant pushes.

To calculate approximate Capture Point locations, we use the Linear Inverted Pendulum Model introduced by Kajita and Tani. For a point mass biped walking at a constant height, this model exactly predicts the Capture Point. However, for a distributed mass biped, it is only an approximation. In order to better predict Capture Points, we learn a correction function to the Linear Inverted Pendulum Model. A Linear Inverted Pendulum maintains a conserved quantity called the orbital energy throughout the stance phase, which traces out trajectories on the phase plot. The equation for orbital energy can be used to calculate a Capture Point by calculating the current energy, predicting the velocity at the support foot transfer, and then setting the next swing orbital energy to zero and solving for the body position. We used two learning methods, one online and one offline, to improve Capture Point prediction. In the offline learning method, the robot is pushed multiple times with a given force magnitude and direction. During each learning trial, the robot starts balanced upright and stationary. Pushes, represented in the video as projectiles, are applied as a constant force for 0.05 seconds. We vary the magnitude of the force from 150 to 550 Newtons, and its direction in the horizontal plane. When the Center of Mass reaches a set horizontal distance from the support foot, the robot predicts a Capture Point and starts to step to that location. For each applied force, several simulation runs are performed, each one resulting in the robot taking a step within a grid centered around the Capture Point predicted by the Linear Inverted Pendulum Model.

We find multiple capture points because the actuated feet allow for a margin of error. These points define a capture region. For failed points we calculate the center of mass position and velocity vectors at the top of swing. These are then used to calculate the residual Orbital Energy. For trials that result in successfully stopping, the residual Orbital Energy is zero.

This process is repeated for five different forces at 10 different angles around the circle. For each of these pushes we calculate the centroid of the capture region and the offset vector from the Capture Point predicted by the Linear Inverted Pendulum model.

We then fit a curve to the angle and magnitude of the offset vector as a function of the angle of the center of mass velocity. Using this corrected capture point, we find significant reduction in residual energy error when compared to using only the Linear Inverted Pendulum Model.

In the online learning technique, we use a Radial Basis Function to represent the learned offsets from the Capture Point predicted by the Linear Inverted Pendulum Model. After each push, the robot predicts where to step to, steps there, and determines the residual orbital energy error. We use the residual energy to estimate the capture point. This estimate is then used to update the weights of the Radial Basis Function. After approximately 500 learning trials, the Radial Basis Function converges and the residual energy error is significantly reduced in further trials.

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