REACTION WHEELS AS “APPENDAGES” TO AID IN UNDERACTUATED BIPED WALKING

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Abstract

The reaction mass pendulum model is a common way to simplify the analysis of upper-body inertial control in humanoid robots by lumping together the head, arms, and torso as a single virtual reaction wheel [1]. Physical reaction wheels have been embedded in the torso of an underactuated biped robot to improve regulation of torso orientation [2]. While the stability benefits of having superior inertial control via reaction wheels are clear, there is a weight penalty associated with including them on a biped. This abstract explores how a reaction wheel can be actuated on every step to mitigate that penalty by enhancing overall energetic efficiency. Specifically, it considers a reaction wheel placed coaxially with the hip in the torso of the five-link planar biped ERNIE shown in Fig. 1. In all cases, the strategy is to keep the angular velocity of the reaction wheel low to reduce friction losses, to prevent gyroscopic effects from unduly resisting desired changes in direction (for a 3D implementation), and to avoid torque saturation in one direction. Gaits are generated via trajectory optimization using a direct transcription approach.

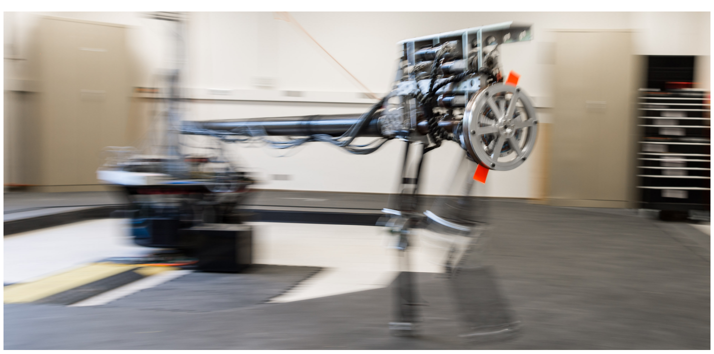

FIGURE 1. Planar, five-link biped ERNIE walking with a reaction-wheel-assisted gait.

Initial simulation work showed that reaction wheel actuation on each step of a periodic gait can reduce specific cost of transport, especially at higher walking speeds and for gaits with longer step lenghts [3]. These efficiency gains are relative to a robot of the same total mass, and actuating the reaction wheel does NOT reduce energy consumption compared to a lighter robot not carrying a reaction wheel. When implemented in experiment, the reductions in specific cost of transport were between 15 and 25%, with the smallest benefits occurring near the optimal walking speed [4]. Three potential mechanisms by which these efficiency gains might be achieved were considered: 1) energy storage and return - absorbing kinetic energy from the biped into the reaction wheel and then restoring it to the robot when advantageous; 2) virtual ankle push-off - storing angular momentum before foot touchdown and restoring it afterward to alter dissipation at touchdown; 3) control flexibility - enabling the gait optimizer to plot a more favorable trajectory through the state space. Collected data were consistent only with this third mechanism. This may be due to the robot’s hip and knee motors offering no opportunity for power regeneration as a result of their heavy gearing. Were these joints directly driven like the reaction wheel, the gait optimization may have been better able to exploit one or both of the other mechanisms.

The energetic benefits of reaction wheel actuation were more significant, at least in simulation, for transient robot motions like speed transitions and disturbance rejection [5]. Aggressive maneuvers such as large single-step accelerations were accomplished with as much as a 60% improvement in specific cost of transport. Benefits declined as the number of steps for a transition increased, and no parallel benefit was seen for deceleration over any number of steps. Similarly large improvements, however, were found for rejecting disturbances in the anterior-posterior direction, and reaction wheel actuation also increased the magnitude of tolerable disturbances.

References

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