REACTION WHEEL ACTUATION FOR STABILIZATION AND EFFICIENCY IMPROVEMENT IN PLANAR BIPEDS.

Abstract

by

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As robotic technology moves out of factories and into broader segments of society, it promises to support a revolutionary improvement in the general standard of living. One of the largest hurdles to this increased use of robotic technology, however, is the inability of current mobile robots to negotiate difficult and delicate terrain in ways that are fast, efficient, and safe. Examples in nature demonstrate the incredible potential of legged locomotion to fill this need, but legged robots have not yet reached this level of performance. This work moves the field toward a better understanding of the design of robust and efficient legged robots by exploring the concept of reaction wheel actuation. This concept consists of the generation of torques on the robot’s body via a high efficiency reaction wheel system (RWS), which operates by accelerating an internal reaction mass. These torques can be used to both improve the stability of the robot and increase its walking efficiency when used in a coordinated manner.

Due to the complex multi-body dynamics of these systems, the effect of design changes on a given performance metric are difficult to estimate. Full body trajectory optimization via direct transcription was employed as the primary tool to better understand the role that an RWS can play in bipedal locomotion. The five-link planar biped ERNIE was used as a basis for this analysis. Combined with a model of
motor and gear losses, this allowed energetic comparisons between a baseline ERNIE model and hypothetical RWS-equipped versions. This showed for the first time that a correctly designed RWS, requiring only a modestly sized reaction wheel and a motor with minimal gear loss, can lead to improved walking efficiency.

Extensive optimization over the full operational walking range showed that a reasonably sized RWS with realistic levels of efficiency can improve walking efficiency by 5-10% over most gaits. Comparison of resulting gaits revealed that optimal RWS use leads to better centroidal momentum regulation, which in turn reduces loads on joint motors in the legs. Simulations of the ERNIE model under virtual constraint control verified these results. For validation, an experimental reaction wheel system was constructed and attached to the ERNIE biped. Walking experiments with ERNIE demonstrated a measurable improvement in walking efficiency for gaits that utilize the RWS, corroborating the results from both optimization and simulation.

For periodic walking, optimization results showed that near regions of marginal dynamic feasibility, reaction wheels can lead to much larger efficiency gains than in more typical operating conditions. RWS use also expands the range of dynamically feasible motions. In aperiodic motions such as speed and step length changes, RWS use is similarly beneficial, with significant efficiency gains in very demanding motions and expanded dynamic feasibility. In large, single-step changes of speed, the RWS can improve efficiency by as much as 60%. When transitions are executed over longer, multi-step duration, RWS use provides benefits similar to those seen in periodic walking.

The potential role of reaction wheels in improving balance was also examined. Design principles for efficient RWS stabilization were derived by combining RWS-based balance controllers with accurate gear and motor models. Stabilization generally demands more RWS torque than steady state walking, but still favors relatively light gearing in order to minimize gear loss and maximize momentum storage potential.
A task space controller for underactuated balancing was developed to compare baseline and RWS-equipped bipeds in terms of balance performance. While the RWS-equipped biped was able to balance and reject large disturbances, the baseline biped was only able to balance for short periods of time.