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# Fast Convergent Gait Generation for Underactuated Spoked Walker with Torso

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**Keywords:** Limit cycle walking, Rimless wheel, Deadbeat control, Gait generation, Uneven terrain.

A rimless spoked wheel or simply rimless wheel (RW) is investigated as the most simplified model of passive dynamic walking. In McGeer's early study on passive-dynamicwalkers, the stability of a RW was analyzed based on the return map. It was also clarified that a passive-dynamic gait of a RW is always one-periodand asymptotically stable because it automatically achieves both constraint conditions for restored mechanical energy and impact posture. The constraint on impact posture is necessary to make the energy-loss coefficient constant. The restored mechanical energy is always kept constant because the step length is constant. It is then shown that the kinetic energy immediately before impact converges to the steady value. The generated passive-dynamic gait is obviously natural and energy-efficient.

On the other hand, applications of inherent passive dynamics to efficient active walking on level ground have been actively investigated. Active dynamic walkers with small actuators are called limit cycle walkers in distinction from passive dynamic walkers, and they can walk on level ground efficiently exploiting their natural dynamics. During the last decade, many energy-efficient walkers have been developed and nowadays they are familiar in the field of robotic bipedal locomotion. The control design, however, has been a continuous process of trial and error and the limit cycle stability remains unclear.

Based on the previous research, fortunately, it has been clarified that a fast convergent gait can be generated by applying a simple output following control to a desired-time trajectory, and that a deadbeat gait can be generated by modifying the system parameters. The deadbeat gait is a walking gait whose discrete state error converges to zero only in one step. It can be said that the deadbeat gait is the optimal one in terms of the convergence speed. Such a fast convergent gait has a tremendous advantage in limit cycle walking on uneven terrain.

Based on the observations, I propose a novel approach: continuous-time output deadbeat control (CODC) based on the discrete-time output deadbeat control (DODC). I introduce the model of an underactuated spoked walker with a torso that can exert the joint torque between the stance leg and torso. The walker can walk forward by controlling the torso and using the reaction moment. In this thesis, first, I propose CODC in which the control input is defined as a linear function of time. By applying this method, the control output which is defined as the relative angle between the stance leg and torso is settled to zero and the mechanical energy lost at impact is successfully restored during the stance phases. Through analysis, I find that a deadbeat gait can be generated by changing the control interval or desired settling time. Second, I investigate the properties of the generated gait and compare the gait efficiency with that generated by DODC through numerical simulations to prove the advantages of CODC. At last, I show some advantages in the gait generated by CODC on uneven terrain and discuss the problems.