Title	両脚支持期を生成する劣駆動2脚ロボットの動歩行解析と転倒に関する考察
Author(s)	大島，正嵩
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Studies on Dynamic Walking and Falling of Underactuated Bipedal Robot that Generates Measurable Period of Double-limb Support

Masataka Ohshima (1110009)

School of Information Science,
Japan Advanced Institute of Science and Technology

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It is well known that limit cycle walkers smoothly walk without placing feet flat on the ground and keep walking with small energy supply . The generated gait is thus energy-efficient and high-speed, and the limit cycle consists of the stance and collision phases. There is a tendency that the inelastic collision for stance-leg exchange is modeled on the assumption that the rear leg leaves the ground immediately after touchdown of the fore leg. The validity of this assumption has been confirmed through experimental walking of rimless wheels, compass-like walkers, and kneed walkers. The generated gait mathematically becomes a limit cycle without containing a measurable period of double-limb support (DLS). In human walking, however, there is a non-instantaneous DLS more than 10% cycle, but the effects and roles of DLS on the gait properties have not been investigated actively in the field of robotic limit cycle walking.

Recently, however, several major results have been reported. Geyer et al. discussed the similarity between human walking and limit cycle walking from the viewpoint of ground reaction forces. They used the model of a planar, elastic-legged compass-like walker without having the leg mass and showed that the walker generates non-instantaneous DLS motion.

Kawamoto et al. also investigated the potentiality of emergence of DLS motion through mathematical modeling and numerical simulations of more realistic spoked walker with viscoelastic-leg frames. They showed that measurable periods of DLS emerge after the instant of touchdown of the fore leg. These early works on telescopic-legged walkers proved that non-instantaneous DLS motion can emerge if the leg frames have redundant free joints. There is a potentiality, however, that walkers with different physical structures generate DLS motion during walking. This paper then considers planar walkers with knee joints and semicircular feet for analysis.

First, we introduce a rimless wheel model with active knee joints. We then numerically investigates the potentiality of the emergence of a non-instantaneous DLS by controlling the magnitude and application timing of the knee-joint torques. Second, we extend the gait analysis to a bipedal walker to understand the physical principles of natural robotic walking and human walking from the viewpoint of DLS effects. In the analysis, we deal with a planar four-linked bipedal walker with active hip and knee joints and semicircular feet. We numerically show that a measurable period of DLS emerges after the instant of touchdown of the swing leg in the absence of the knee-joint torques. We also perform parameter studies to clarify the tendency of emergence of DLS motion with respect to the robot's physical parameters such as the leg mass and foot radius. Furthrmore, we discuss the limit cycle stability from the viewpoint of the convergence rate of the state error norm. We numerically show that the stability significantly changes with respect to the ratio of the period of DLS to the step period. Based on the results obtained, we discuss the mechanism of how elderly people fall while walking.