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Generation of High-speed and Robust Gait for Biped Robot with Dynamic Absorbers on Leg Frames

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Limit cycle walkers generate energy-efficient walking gaits by using the natural dynamics inherent in the system. Recently, the studies on legged robots focusing on the leg stiffness have been conducted. Kawamoto and Asano clarified that adaptability to uneven terrain can be improved by using viscoelastic leg frames through numerical simulations and experiments. They showed that viscoelastic-legged walkers have advantages to overcome steps and continue sustainable walking on various road conditions without changing the walking speed so much. They also showed that rigid-legged walkers have an advantage of generating faster walking gaits than viscoelastic-legged ones but have a disadvantage to adapt to uneven terrain. The leg viscoelasticity tends to create non-instantaneous double-limb support motion and this significantly decreases the walking speed. The center of mass (CoM) orbit, however, becomes smoother and this makes the walker overcome the potential barrier at mid-stance easily. Similar results have also been reported by Tanaka *et al.*

The above facts imply that soft leg-frames are important for improving the adaptability and maneuverability of the generated gait in return for high-speed movement. We humans have both advantages of the leg stiffness and softness and can easily generate high-speed and highly adaptive

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walking gaits. We should reconsider how the robot's leg frames should be designed to reproduce the high performance of human walking.

The basis of the leg frames should be made of a solid material to achieve high-speed walking motion, while softness of the legs should be added indirectly to avoid non-instantaneous double-limb support motion emerge. The importance of robot's internal softness reproduced as an wobbling motion has also been reported by Hanazawa *et al.* and Ackerman *et al.* In these early works, however, the indirect softness was given as an additional linkage to the robot's body frame.

Based on the observations, in this paper we propose novel limit cycle walkers that have dynamic absorbers on the leg frames. We add dynamic absorbers parallel to the rigid leg frames for the purpose of indirectly reproducing the dynamical effect of viscoelasticity while keeping high-stiffness of the legs. It is then expected that efficient passive or underactuated walking gaits can be generated without decreasing walking speed of the rigid-legged walker.

First, we introduce the model of a compass-like biped robot that added dynamic absorbers parallel to the leg frames and numerically analyze the gait properties according to the change in the viscoelastic coefficients. We show that speeding-up of passive compass gait can be achieved by the effect of the dynamic absorbers during walking. We discuss the speeding-up mechanism mainly from the viewpoint of flattening of the CoM orbit. In addition, we also show that some strange gaits are generated where the dynamic absorber motion is more dominant. Second, we extend the analysis to an underactuated biped model that walks on level ground and show that speeding-up of level gait can also be achieved by the effect of dynamic absorbers through numerical simulations. Furthermore, we investigate the adaptability of this model to uneven terrain such as a small step and the rugged terrain that follows a Gaussian distribution. We show the adaptability of the walker is higher than that of the rigid-legged walker.