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Gait Analysis and Efficiency Improvement of Combined Rimless Wheel with Wobbling Mass

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After the study of passive dynamic walking by McGeer, various studies aiming at efficient dynamic walkers have been widely conducted by many researchers. It has already clarified that efficient walking can be achieved by applying the principle of passive dynamic walking. Most of the previous studies have mainly treated biped walkers. Recently, however, multilegged walkers have also been studied. Smith and Berkemeier analyzed a coupled passive dynamic walker and showed that stable passive gaits are generated with suitable parameter settings. In their simulation model, however, there were many approximations such as linearization and trigonometric. Remy et al. investigated a quadruped walker that consists of two compass-like biped and numerically showed that the fore and rear legs' motion synchronizes. Yoshikane et al. also investigated what effect the trunk had on the gait properties using a quadruped passive dynamic walker " Jenka ". Inoue et al. investigated modeling and analysis of passive dynamic walking of a combined rimless wheel (CRW) that consists of two identical eight-legged rimless wheels (RW), and showed that speeding-up is achieved by adjusting the phase difference between the fore and rear legs through numerical simulations. The validity was also confirmed by using an experimental machine. They explained the speeding-up mechanism from the potential barrier (PB) point of view; PB is the posture where the potential energy is maximized. They showed that the orbit of the whole center of mass (CoM) significantly changes in accordance with the phase difference, and that the CoM orbit becomes flat where the phase difference approaches near half of the hip angle. The moving distance of CoM in vertical direction is reduced by the phase difference and this was considered the cause of speeding-up. Overcoming PB becomes easier by flattening the CoM orbit. Single RW cannot change the CoM orbit, whereas CRWs can change it by adjusting the phase difference. This is an advantageous of CRWs in the sense that speeding-up can be achieved without any power input, and implies the importance of the flatness of CoM orbit in speeding-up of passive dynamic walking.

Based on the observations, in this thesis we propose another method for flattening CoM orbit; the use of a wobbling mass. It is expected that the whole CoM orbit during motion becomes flatter by the vibration of the wobbling mass inversely to the up-and-down motion of the CRW. There are several related works. Alexander showed in his experiment that viscera of running dog act as a wobbling mass and its vibration supports breathing. Rome et al. developed the suspended lord backpack (SLB) that generates electricity by moving up-and-down of the trunk. The SLB consists of a pack frame and load part suspended by springs from the frame. They also showed that suspended load reduced peak force and cost of walking than the same weighted rigidly backpack. Nakanishi et al. developed a quasi-passive dynamic walking robot using an active wobbling mass moving from side to side inside the body, whereas Kibayashi et al. also developed a quadruped robot using a wobbling mass that swings on the robot body. They showed the effectiveness of the wobbling mass movement on the gait generation, but did not focus the CoM orbit during motion. In this thesis, we investigate the effect of the wobbling mass on the passive-dynamic gait of a CRW from the CoM orbit point of view. First, we develop the mathematical model of the CRW with a wobbling mass incorporating a spring and damper. Second, we numerically analyze the passive-dynamic gaits through numerical simulations. We show that the walking speed increases by the effect of the wobbling mass and the gait efficiency changes with respect to the elasticity. The wobbling mass exhibits inverse phase synchronization to the CRW in the case that the elastic coefficient is small and the whole CoM orbit becomes flatter than the case with fixed wobbling mass. Whereas it exhibits normal phase synchronization in the case that the elastic coefficient is large and CoM orbit becomes more vigorous than the case with fixed wobbling mass. In this case, the wobbling mass enhances the revolving motion of the whole CoM. We also discuss the transition from inverse to normal phase synchronization from the frequency point of view. Finaly, the validity of the simulation results is verified using an experimental CRW machine.