Title	揺動質量と脚運動の最適化に基づく連結型リムレスホイールの低摩擦路面上の安定歩容生成
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Stable Walking Gait Generation on Low-Friction Surface for Combined Rimless Wheel Based on Optimization of Wobbling Mass and Leg Motion

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In recent years, research on foot-based robots with high adaptability has gradually come into view. Combine rimless wheel is structurally highly stable and does not fall on low-friction pavements, and based on this, we conjecture that a combined rimless wheel can generate a stable gait even on low-friction pavements. Based on this point, this paper discusses the feasibility of the combined rimless wheel robot to form a stable gait on a low-friction road surface. First, we control the robot by adding a vibrator to the center of the body of the combined rimless wheel to indirectly influence the robot's center of mass (COM) and the speed of the robot. This potential mechanical effect caused by shaking the oscillator profile excitation is promising for application in more robots, so we are ready to make a new attempt. We can hypothesize the combined rimless wheel structure as a quadruped robot with stable mechanics, and he will be highly adaptable on irregular and dangerous surfaces. The latest robots such as Bigdog and ANYmal, who can perform a variety of complex movements, can pull the center of gravity back by calculating the landing posture even if the center of gravity produces a shift in the target orbit. However, this complex structure consumes a lot of energy.In this kind of real-time feedback system, high speed and low energy consumption become a very big problem. However, a rimless wheel with a stable structure, as a high-efficiency limit cycle walking robot, is widely used in the field of bipedal and quadrupedal robots. We have seen the excellent performance of the combined rimless wheel in terms of energy consumption in our passive walking experiments. If on a flat surface, we can add torque to the wheel to replace the driving force provided by gravity in passive walking, and the energy lost each time the foot touches the ground can be rebalanced by the torque to generate a stable limit cycle. Moreover, in the experiments on passive walking, we found that we can control the robot cycle, improve the robot energy loss, and even improve the robot walking efficiency by using the shaking mass in the combined rimless wheel. So in this experiment, we will try the method of adding the rocking mass to indirectly excite the robot system. The advantage of this method is that it is easy to install and various systems can carry a small volume of shaking mass, and through the periodic motion of the shaking mass, our robot will also generate periodic oscillations, and by this method, limit-cycle walking on low friction road is achieved.

In the previous experiments, we did not fully discuss the effects of various parameters on the experimental results, so in this simulation, we will fully discuss the length of the oscillator trajectory, the motion period, and the mass of the oscillator, and finally, the friction coefficient of the ground. To simplify the model and reduce the uncertainty in the experiment, we set the motion cycle of the oscillating masses to be the same even in the case of double oscillating masses, and we set the purpose of this study as to how to use the oscillating masses to generate a stable limit cycle walk. Rimless wheel model on low friction surfaces. Initially, we set up the model as an eight-foot combined rimless wheel model, In the rimless wheel experiment, the number of feet affects the amount of energy lost in each collision, and we believe that using an 8-legged model in this experiment is more conducive to our simulation analysis. We used a rigid rod to connect the ends of the two rimless wheel feet, so that the phase difference between the front and rear wheels would not come out in the experiment, reducing the possible branching of the test and making our test results more focused on the impact of the shaking mass. Our model grounded feet and the middle connecting rod, forming a parallelogram, the connecting rod always remains parallel to the ground. This property allows our oscillator to be independent, and the moment added to the rimless wheel can be seen as acting directly on the ground. By such a structure, we make a small interference between the oscillator and the parallelogram, so that the CRW system travels on a low friction road.

In Chapter 2, we added two wobbling masses at the center of the connecting rod, one in the X direction and one in the Z direction. Initially, we were unsure of what input to apply to the wobbling masses that would allow the robot to achieve a limit cycle walk, and we designed the trajectory of the connecting oscillator like a sine wave, setting the amplitude of the sine wave to 0.1 to 1 and the frequency of the sine wave to 0.1 to 1. This gives us three parameters, each with an interval of 0.05, and we will measure 8000 sets of data, and we will discard the data that fail to walk. In between, we filtered out the most frequent groups, defined as typical inputs, and we performed position analysis, limit cycle analysis, and also ground reaction force analysis on these groups. We found that at some point, our ground reaction force in the z-direction will be less than zero, which means that our means that our robot system is off the ground, which makes our analysis meaningless. Therefore, we have improved the control in Chapter 3.

In Chapter 3, we will use two inputs to reach two output targets. We calculate the center of the system as X_{com}, our first output target as $\ddot{X}_{\mathrm{com}} = 0$, and the second output target as θ_d as a quintuple function. We change the output target to $\ddot{Z}_{\mathrm{com}} = 0$, θ_{d} as a function of five, which is the initial state of the system we have to determine by the dichotomous method, this initial state range is very narrow, and the radius of motion of the X oscillator is two meters, far beyond the volume of our system, which is difficult to be applied in the real environment, so we give up this method.

In chapter 4 we use a 2-DOF wobbing mass, the angle between the orbit of the rocking mass and the middle linkage can be varied, this idea is thanks to equestrian sports, our oscillator imitates yardage athletes and can rock up and down, left and right to control its attitude, we also add a torque. Our output control target becomes $F_{X\text{com}} = 0$, $F_{Z\text{com}} = mg$, θ_d as a quintuple function. First, we simulate this system on a high friction ground, and if we can achieve our goal, we then extend this method to a frictionless ground. With this control method, at this point, we get a USSW gait, and in the second half of Chapter 4, we add this system to a frictionless ground, because the center does not tend to move in both the X and Z directions, so we can determine that this system can walk in a frictionless environment. Finally, for this experiment, what we will do in the future is to improve the method in Chapter 2, there must be a corresponding initial state that can generate a stable gait under the first control method, but we do not know how to find this initial state now, for the content of Chapter 4, we may try to change the control output in the future, such as changing the output to Z_{com}, θ_d, sine wave, and we will make a real machine in the future to verify the theory we just got.