A Conveyor System Based on Walking Theory of Underactuated Locomotion Robots

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Using underactuated locomotion system is expected to be lighter and more energy efficient than the conventional robot which used actuators for all robot joints in that it can be moved with a small number of actuators. One of the methods for underactuated locomotion system is utilizing a wobbling mass. This method realizes the underactuated locomotion by entraining locomotion frequency of robots to vibratory frequency of the wobbling mass, thereby adjusting the vibration frequency of the wobbling mass control the locomotion speed of robots. The method has been used to control various locomotion robots. Cau proposed the control method to generate 3D quasi-passive walking on uphill, downhill and level-ground by utilizing a mechanical oscillator and spherical foot. Hanazawa achieved to control walking speed for a biped robot with a rimless wheel by utilizing up-down vibration of a wobbling mass when level-ground walking. In the previous studies, the wobbling mass to entrain walking frequency is included by the robots, there is no study utilizing a wobbling mass outside a robot. In this research, I hence propose that utilizing a vibration of a conveyor outside the robot realizes gait generation of an eight-legged rimless wheel which is a simple model of walking robots, and control conveyance speed. Asano already considered dynamics of a moving floor for stable walking of the robots which is composed by rimless wheels. Entrainment by input of vibrating to walking robots by a floor, however, has not been discussed. I thus verify that applying vibration input from the conveyor occurs the entrainment like utilizing inner wobbling mass of previous research.

A transport system which carries objects utilizing vibratory stage is a general technology, thus it is used in a wide variety of fields. The reason why using vibrating conveyor systems widely is that vibrating conveyor systems can realize continuous object transfer by a simple mechanism. In addition, it can distinguish, sort and align objects to be transferred at the same time as object transfer by only itself, contributing to simplification and automation of equipment. The conventional vibrating conveyor systems, however, are only considered as to carry objects on the stage by rotating, jumping or sliding motion by the vibration of the stage, thus there is no consideration for dynamics details of each object. The conventional systems are furthermore not suitable for transport large objects utilizing vibration. In this study, I therefore apply the principle of underactuated walking robots to the vibratory conveyor system, thereby control the conveyance speed of the RW.

This study is expected to contribute to future research on carrying large object, which has been difficult to transport using the conventional vibratory conveyor system. It is furthermore expected that the proposed conveyance system is applied to a rehabilitation system for human walking in order to prompt and generate a walking motion of the object from outside by the vibration of the stage.

First, I introduce a simple mathematical model which is two-DoF of the vibratory conveyor system and explain a design method of a control system for the model. The system vibrates the stage by input for a telescopic joint under the stage, transport by letting the passive rimless wheel walk. I investigate the influence for the rimless wheel gait by vibration of the conveyance stage in the model, and confirm the entrainment of vibratory frequency to walking frequency. In addition, I investigate the influence of the entrainment by adjusting physical parameters in the model.

Second, considering the adaptation to the actual machine from the before model, I extend the mathematical model of the vibratory conveyor system to four-DoF. The conveyor system is composed by an active rimless wheel, a conveyance stage and a passive rimless wheel. The active rimless wheel which connects a motor vibrates the conveyance stage linearly, whereas the passive rimless wheel is transported by the vibration of the conveyance stage. I investigate the influence for the passive rimless wheel gait by vibration of the conveyance stage in the almost same way. I confirm the influence of the entrainment by adjusting physical parameters in the model, and compare the simulation results of the extension model and the before model.

Third,I verify to occur the entrainment using the prototype experimental system of the vibratory conveyor system, and confirm the experimental results show similar trends of the simulation results. The experimental data of the angular velocity and angular acceleration of the passive rimless wheel are detected by a sensor put on the passive rimless wheel, and the angular position is then estimated by using Kalman filter.

In this research, I performed the following matters.

- I decided a specification the vibratory conveyor system using the linear joint and derived a mathematical model.
- I performed the motion generation of the proposed conveyor system, the transition tendency of the walking frequency for the passive rimless wheel to the vibration frequency in the change of the physical parameters was confirmed.
- In order to consider the adaptation to the experimental machine, I decided a specification the vibratory conveyor system using the active

rimless wheel and derived a mathematical model.

- I simulated the motion generation of the extend vibratory conveyor system. and I investigated the transition tendency of the walking frequency for the passive rimless wheel.
- I developed the prototype machine which satisfies the specifications of the proposed vibratory conveyor system.
- I verified utilizing the prototype experimental system of the vibratory conveyor system, and confirmed that the experimental results showed a similar tendency to the simulation results.

In the experiment, due to lack of torque for the motor, the experiment was limited to a part of the range. In the future, I will improve the experimental machine and verify the actual machine in a wider range of vibration frequencies. Furthermore, it is necessary to devise a control method to stabilize the gait of RW_1 for the practical use of this transport system. In addition, I control the walking speed of the only rimless wheel to the vibratory conveyor in this study, thus it is need to control the walking speed of the multiple rimless wheels.