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Balancing Control of Bicycle Robot Using PID Control

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Abstract: This paper discusses on the balance control of bicycle robot. The reaction wheel pendulum is used to control the balance. The PID controller, based on the non-model, is used. The performance of controller is confirmed by the experiment.

Keywords: Reaction wheel pendulum, Bicycle robot, PID control, Balancing control.

1. INTRODUCTION

The development of technology for the convenience of humans has been evolving day by day. The leading sector in this development of technology is the robotics. This field is applied to many applications, including the industrial robots and unmanned robot. Among them, the research of unmanned robot is actively in progress. Most of unmanned robot was developed based on the four-wheel and six-wheel. The robot based on the four-wheel or six-wheel is hard to drive in the special environmental factor, such as the confined space. To solve the matter, a lot of research on the two-wheeled robot is in progress. The two-wheeled robot called the bicycle robot can freely drive in the narrow and the confined space, however, the robot has the characteristics of unstable structure. Many control methods have been proposed in order to improve the stability of the robot which has the unstable characteristics. This paper will also cover the control method for improving the stability of the robot. However, proving the dynamic model of robot is too complex to implement in real time.[1] Therefore, the PID controller which is relatively easy and simple to implement is proposed to control the robot. To control the balance of robot, we assume that the robot's body and the disk as a reaction wheel pendulum. The bicycle robot is controlled the way which rotates the disk tilted in the direction of the robot to generate the acceleration instantaneously, and uses the force that the robot is tilted in the opposite direction of rotation due to the inertia of disk and the rotational reaction.

The organization of this paper is as follows. In section 2, the modeling of robot for the simulation and controller will be explained. In section 3, the performance of the designed controller is verified through the experiment. Lastly, in section 4, conclude this paper.

2. DYNAMICS

In this section, the dynamic equations are derived to confirm a performance and controllability of designed controller by simulating the system. The dynamic equations are obtained using Lagrange equation.

2.1 Dynamics of Bicycle Robot

The bicycle robot is assumed that the robot's body and the disk as the reaction wheel pendulum.[2-3] As shown in Fig. 1, set the robot's coordinate. L_2 is the distance from the bottom to the center of the disk. L_1 is the length from the bottom to the center of the robot's body. R_D is the radius of the disk, θ_1 is the displacement of rotation of the robot, and θ_2 is the displacement of rotation of the disk. M_1 denotes the mass of the body and M_2 denotes the mass of the disk.

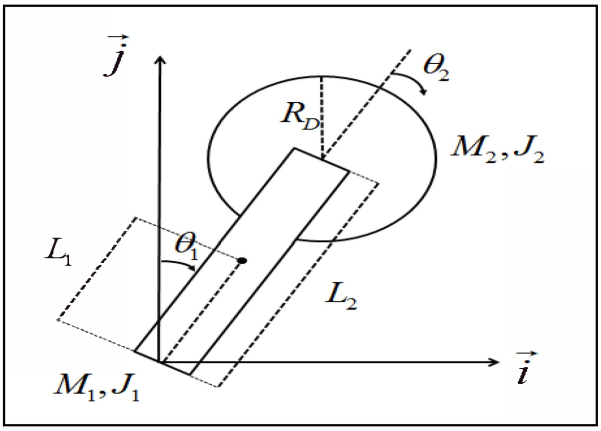

Fig. 1 The model of the bicycle robot

In this paper, the dynamic equation is obtained by using the Lagrange equation. To obtain the Lagrange equation, the Lagrangian should be known. The Lagrangian is obtained by using the kinetic energy and the potential energy. Therefore, kinetic energy and the potential energy of the bicycle robot need to obtain first. $\vec{r_1}$ is the position vector of the body, $\vec{r_2}$ is the position vector of the disk.

$$\vec{r_1} = L_1 \sin\theta_1 \vec{i} + L_1 \cos\theta_1 \vec{j} \tag{1}$$

$$\vec{r_2} = L_2 \sin\theta_1 \vec{i} + L_2 \cos\theta_1 \vec{j}\,. \tag{2}$$

The velocity vector can be obtained by derivative of the position vector. The translational kinetic energy is got using the above equations.

$$T = \frac{1}{2}M_1(\vec{v_1}\bullet\vec{v_1}) + \frac{1}{2}M_2(\vec{v_2}\bullet\vec{v_2}) + \frac{1}{2}J_1\dot{\theta}_1^2 + \frac{1}{2}J_2(\dot{\theta}_1+\dot{\theta}_2)^2 \tag{3}$$

Here, J_1 denotes the rotational inertia of body and J_2 denotes the rotational inertia of disk. Then, obtain the potential energy, V.

$$V = M_1 g L_1 \cos\theta_1 + M_2 g L_2 \cos\theta_1 \tag{4}$$

Now, we can get the Lagrangian.

$$\begin{aligned} L &= T - V \\ &= \frac{1}{2}M_1(\vec{v_1}\bullet\vec{v_1}) + \frac{1}{2}M_2(\vec{v_2}\bullet\vec{v_2}) + \frac{1}{2}J_1\dot{\theta}_1^2 \\ &\quad + \frac{1}{2}J_2(\dot{\theta}_1+\dot{\theta}_2)^2 - M_1 g L_1\cos\theta_1 - M_2 g L_2 \cos\theta_1 \end{aligned} \tag{5}$$

Finally, the Lagrangian equation is the Eq. (6).

$$\frac{d}{dt}\frac{\partial L}{\partial \dot{\mathbf{q}}} - \frac{\partial L}{\partial \mathbf{q}} = \tau_q, \mathbf{q} = [\theta_1 \quad \theta_2]^T \tag{6}$$

Substitute the Lagrangian to the Lagrange equation. The dynamic equation of bicycle robot is the Eq. (7) and (8).[4]

$$(J_1 + L_1^2 M_1 + L_2^2 M_2)\ddot{\theta}_1 - g(L_1 M_1 + L_2 M_2)\sin\theta_1 = -\tau \tag{7}$$

$$J_2(\ddot{\theta}_1 + \ddot{\theta}_2) = \tau \tag{8}$$

When using the MCU to control the robot, PWM is generally used. For this reason, the input should be changed the torque to the voltage.

$$\tau = nK_t i + f_m(\dot{\theta}_2 - \dot{\theta}_1) \tag{9}$$

$$L\dot{i} + R_m i = v + K_b(\dot{\theta}_2 - \dot{\theta}_1) \tag{10}$$

K_t denotes the torque constant, f_m denotes the friction factor of motor, and L denotes the inductance of motor. R_m is the resistance of motor and K_b is the back EMF constant. By using the Eq. (9) and (10), solve the relational expression on the current-voltage equation.

$$\tau = \frac{nK_t}{R_m}v - \left(\frac{nK_t}{R_m}K_b + f_m\right)(\dot{\theta}_2 - \dot{\theta}_1) \tag{11}$$

The Eq. (11) substitutes the Lagrange equation. Now, the robot can be controlled by the PWM.

2.2 Designed Controller

Figure 2 indicates the controller of bicycle robot.

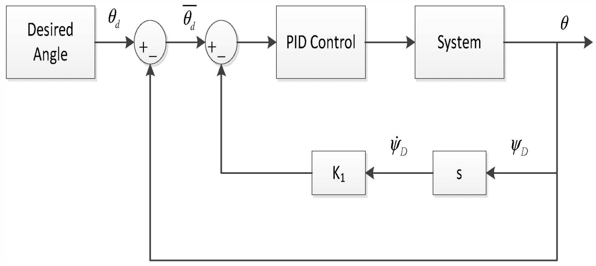

Fig. 2 Controller of Bicycle robot

The input is the slope of the robot's body. When the robot is a parallel, the angle of robot is zero. So the desired angle is zero. θ denotes the angle of the robot body. The controller is designed based on the PID controller and feeds back the angle of the robot and the $\dot{\psi}_D$ term.

The bicycle robot is controlled by rotating the disk instantaneously. When the robot keeps the balance, the important thing is to find out the exact balance point. If not, the robot tries to maintain the balance continuously on the tilt. The rotational velocity of disk gradually increases. Eventually the robot loses the balance, because the motor torque that can be output is not infinite. To complement this matter, the controller feeds back the $\dot{\psi}_D$ term. The $\dot{\psi}_D$ term can change the angle of input as the velocity of disk increases.

3. EXPERIMENT

3.1 Simulation

In this part, to confirm the performance of controller, make a simulation using the dynamic equation, derived in section 2, through the MATLAB Simulink. The result of simulation is shown in Figure 3.

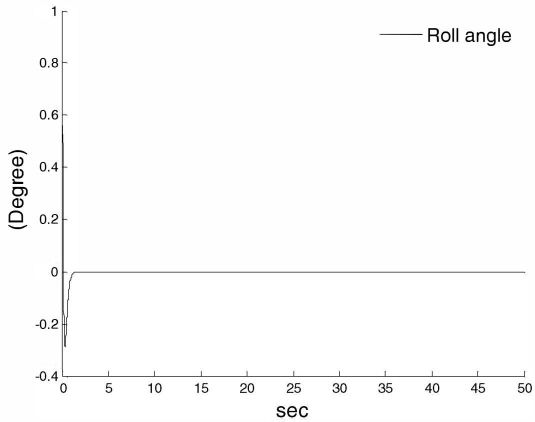

Fig. 3 Result of simulation

As seen Fig. 3, the system can control the balance stably.

3.2 Result of experiment

Now, the designed controller applies to the actual system. The $\dot{\psi}_D$ term is an important role when control the bicycle robot. Fig. 4 shows the result when making the experiment without the $\dot{\psi}_D$ term.

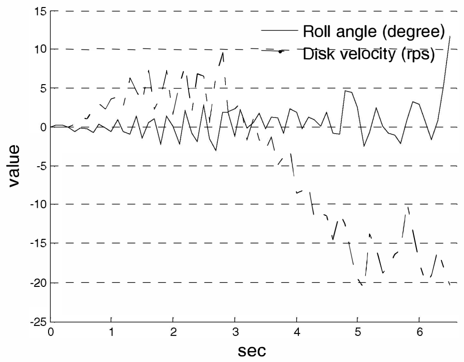

Fig. 4 Result of experiment without the $\dot{\psi}_D$ term

The robot tries to keep the balance, increasing the motor velocity. However, shortly afterwards, the robot loses the balance.

Fig. 5 shows the result when apply the $\dot{\psi}_D$ term.

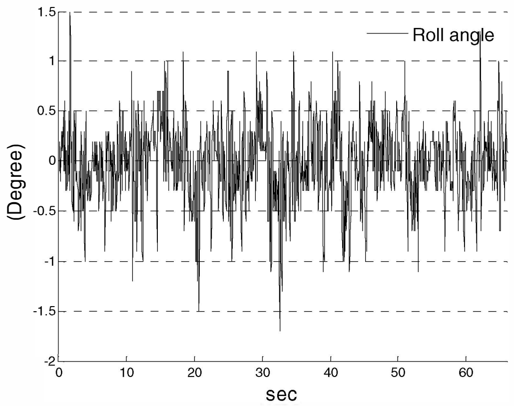

Fig. 5 Result of experiment with the $\dot{\psi}_D$ term

In the case that apply the $\dot{\psi}_D$ term, the robot control the balance stably within plus or minus one degree.

4. CONCLUSION

In this paper, the bicycle robot is assumed that the robot's body and the disk as the reaction wheel pendulum. The PID controller, based on the non-model, is designed to control the attitude. To complement the increasing velocity of disk caused by the offset error, the disk speed feeds back to the controller. As a result, the bicycle robot keeps the balance stably, even though the offset error occurs. Through the experiment, the designed controller is confirmed that the proposed controller is suitable to control the robot. In the future plan, we will study on the straight and curved driving.

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