Development of a Balancing Robot with 2-wheels using the Smart In-Wheel Motor

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Abstract

A Balancing Robot with 2-Wheel using a Smart In-Wheel Motor based on an inverted pendulum model was introduced. Lately, research has been widely carried out for the inverted pendulum system. It because inverted pendulum systems have non-linearity characteristics, so it is an example of a good model to evaluate the performance of the controller. In this paper, a fuzzy logic control system design based on an inverted pendulum model is proposed to control a Segway-type robot, which is an inverted pendulum mobile robot. By designing a fuzzy logic system for control of the robot, the usefulness of control performance was confirmed, and measures to simplify the complexity of the controller design and to reduce the complex calculations of the controller were proposed.

Keywords: In-Wheel Motor, Inverted Pendulum Model, Control System, Segway-type, Balancing Robot

1. Introduction

Lately, research on the inverted pendulum system has been widely reported. The reason for this is that because inverted pendulum systems have non-linearity features, it can be a good model to evaluate the performance of the designed controller. Because of this, there is a great deal of research on inverted pendulum mobile robots both in Korea and overseas. An inverted pendulum mobile robot is a system with added mobility by the use of dynamic capability for adjusting the inverted pendulum's balance. This balancing system has a similar control method to that of a person who maintains their balance on two legs, and to a biped robot that was made by referring to a person moving towards a designated spot.

The Smart In-Wheel Motor is a motor control system which combines a motor, reduction gear, motor driver, controller, sensor and a communications system inside the wheel. This type of motor has the advantage of being easy to use because other additional devices are not needed. In particular, where it is used in a mobile robot, the substructure of the robot is simplified, and the placement of such items as the battery and each higher level control sensor is made easier. In this paper, by using the Smart In-Wheel Motor with these advantages, a 2-Wheel Balancing Robot was produced based on an inverted pendulum control mode. A fuzzy logic control system was applied to this robot.

The 2-Wheel Balancing Robot, such as the Segway, is a robot which is capable of moving, and is based on an inverted pendulum system as proposed by Kapitza in 1965. Unlike the typical scooter with two wheels attached in series, the Segway has two wheels connected in parallel form, so it reduces the 2D area, so it can run smoothly in a narrow area. A mobile robot which employs a moving platform with an inverted pendulum mechanism, requires
additional control performance in order to maintain balance. This balancing function does not perform properly in the case of excessive disturbance. The research was carried out on the design of a fuzzy logic control system to control a 2-Wheel Balancing Robot which is an inverted pendulum robot. First, the dynamic model of an inverted pendulum mobile robot that is a control target system was analyzed, and by designing a fuzzy logic controller the usefulness of control performance was confirmed. In this paper, a simplified design of a fuzzy logic control system is presented, and this led to features such as a simplified control system design and to a reduction in complex calculations. Finally, these features were demonstrated through simulation.

2. Segway-type Robots

The schematic structure for deriving the equation of motion is shown in Figure 1. Based on this, this leads to the equation of motion of the control target system.

\[
\left( M_W + \frac{J_W}{r^2} \right)\ddot{\theta} + M_W \frac{H}{r} \cos \theta - M_p \frac{l}{r} \sin \theta = M_p \frac{l}{r} \sin \theta - \tau
\]  

(3)

3. System Design

The system presented in this paper consists of a Smart In-Wheel Motor and a mobile robot platform which uses this, and a fuzzy logic controller for controlling the robot was designed. Smart In-Wheel Motor refers to a kind of motor, which has such components as the motor, reduction gear, a motor driver, a controller, an encoder, and a current sensor all inside the wheel. This arrangement has a simple structure and is suitable for the driving parts of such things as robots. In this paper a 200W Smart In-Wheel Motor is used. Each Smart In-Wheel Motor, by using a Controller Area Network (CAN), transmits and receives the state of the motor and various controller commands from the outside. Therefore, the control of the motor’s PWM, speed, and current is possible with only four wires, because each motor’s control includes power and CAN communication.
Two types of Fuzzy Logic Controller (FLC) are largely required to control Segway-type mobile robots. These are the “Distance FLC” for position control and “Balance FLC” for balance control.

Inputs for the Distance FLC are both the error signal of the difference between the robot’s current position and the setting position of the robot, and the change signal about these errors. The output is the weighted error angle of the pole for controlling the robot’s movement.

In this paper a FLC was designed for a Smart In-Wheel Motor and Balancing, and based on this a 2-Wheel Balancing Robot was created. The robot is composed of two In-Wheel Motors and LRF and camera for acquiring environmental information about the forward traveling path. It includes a line tracking sensor for detecting the tracking path. In addition, control was performed using an ARM core based 32-bit microprocessor.

The input variable of the balance FLC is the sum of the current value of the pole angle $\theta$ and the weighted error angle of the pole which was the output of the Distance FLC. The output variable is the torque for the motor control.

The fuzzy membership function and control rules for Balance FLC can be set up and derived in a similar way to the Distance FLC. Based on this design, by connecting a complete fuzzy logic controller, a simulation of the entire system can be performed.

4. Simulation and Results’ Analysis

In general, with regards to the Segway-type mobile robot, which is a nonlinear system, simulation is carried out by connecting it to a fuzzy logic controller like that designed in Section 3.
The simulation results for torque and the displacement ($\delta_1$) of the robot are shown in Figures 8 and 9.

![Figure 8. Simulation results of torque.](image)

![Figure 9. Simulation result of displacement $\delta_1$.](image)

In this paper a 2-Wheel Balancing Robot was produced using a Smart In-Wheel Motor. In addition, a FLC using an inverted pendulum model was designed, and this was applied to a real robot.

In this research, while the sensor system was constructed for obtaining environmental information of various surroundings of the produced robot, further algorithm research is needed for testing a robot in real conditions.

5. References

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