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Neuro-Fuzzy Control for Balancing A Two-wheel Mobile Robot

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Abstract: This paper presents neuro-fuzzy control design for balancing a two-wheel mobile robot. A TSK neuro-fuzzy controller is designed for controlling the robot. The neuro-fuzzy control scheme is tested under uncertainties when a weight is placed to ruin the balance. Experimental studies are conducted to compare the performances between PID control scheme and neuro-fuzzy control scheme.

Keywords: Neuro-fuzzy control, two-wheel robot, balancing control.

1. INTRODUCTION

Two-wheel self-balancing robots are a challenging system in the view of control applications. It is characterized as a highly nonlinear and nonholonomic system. An increase of the mobility with two wheels is an asset, but a decrease in the stability should be considered.

There are various types of two-wheel mobile robots from small sized robots to large sized robots in the literature [1]. Small sized robots are mainly used in the control education as shown in Fig. 1. Segway is a typical large robot that has accelerated the research on two-wheel robot systems.

Challenging control points of the robot are less inputs and more states which is an underactuated system. From linear control methods to intelligent control methods, many control schemes have been presented to have the better control performances.

In general, PID control methods work for balancing the robot, but suffer from uncertainties such as changes in robot parameters and environment. Although balancing can be maintained, position control accuracy is poor. Therefore, intelligent control schemes are preferred to improve the performance under the uncertainties. Neural network control or fuzzy control applications have been presented [2].

In this paper, a combined structure of neural network and fuzzy logic, a TSK neuro-fuzzy control scheme, is introduced aiming the robust behavior under uncertainties. Experimental studies of balancing the two-wheel robot are conducted.

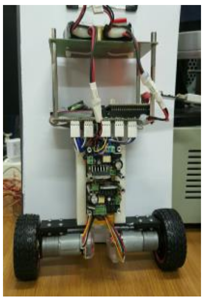


Fig.1 Two-wheel mobile robot

2. CONTROL SCHEMS

2.1 PID Control

Torques for the right and left wheels are given as

$$
\begin{aligned}
\tau_R &= K_1(\psi_d-\psi)+K_2(\dot{\psi}_d-\dot{\psi})+K_3\int_0^t(\psi_d-\psi)dt \\
&+K_4(\phi_d-\phi)+K_5(\omega_d-\omega)+K_6\int_0^t(\phi_d-\phi)dt \\
&+K_7(p_d-p)+K_8(v_d-v)+K_9\int_0^t(p_d-p)dt \\
\tau_L &= K_1(\psi_d-\psi)+K_2(\dot{\psi}_d-\dot{\psi})+K_3\int_0^t(\psi_d-\psi)dt \\
&-K_4(\phi_d-\phi)-K_5(\omega_d-\omega)-K_6\int_0^t(\phi_d-\phi)dt \\
&+K_7(p_d-p)+K_8(v_d-v)+K_9\int_0^t(p_d-p)dt
\end{aligned} \tag{1}
$$

where *Ki* is the controller gain.

Fig.2 shows the PID control block diagram.

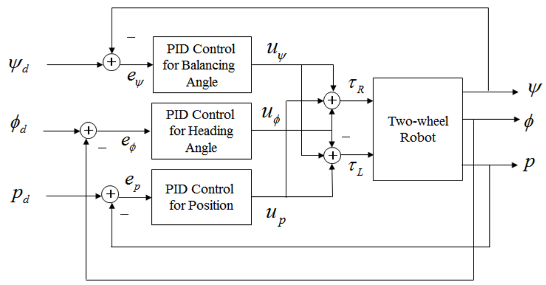


Fig. 2 PID control scheme block

2.2 Neuro-Fuzzy Control

Neuro-fuzzy control scheme is used for the balancing angle and position control as shown in Fig. 3. The neuro-fuzzy structure is shown in Fig. 4.

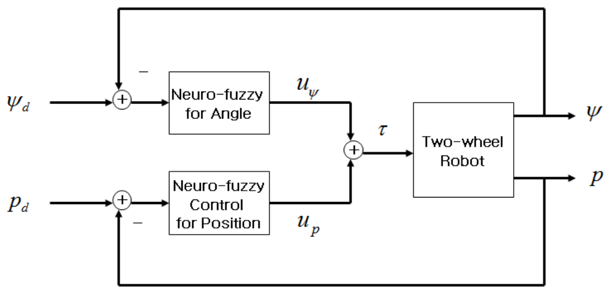


Fig. 3 Neuro-fuzzy control scheme block

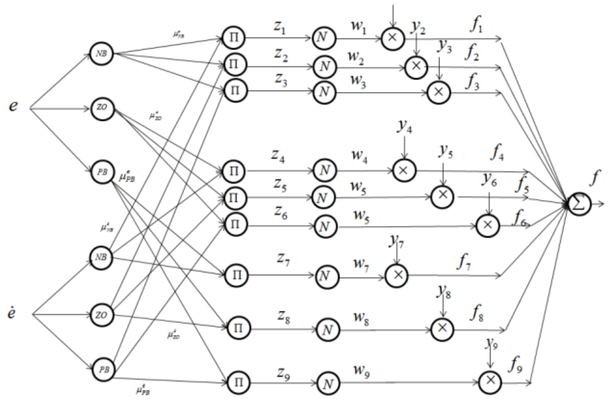


Fig. 4 TSK Fuzzy structure

The fuzzy membership value is defined as

$$\mu_{ij} = G_i^j(m_{ij}, \sigma_{ij}) = \exp[-(\frac{x_i - m_{ij}}{\sigma_{ij}})^2] \tag{2}$$

Two membership values are multiplied as

$$z = \mu_{G_e} \cdot \mu_{G_{\dot{e}}} \tag{3}$$

Then it is normalized as

$$w_k = \frac{z_k}{\sum_{k=1}^{M} z_k} \tag{4}$$

It is multiplied by the input function

$$f_k = w_k y_k \tag{5}$$

where the input function is given as

$$y_k = p_k e + q_k \dot{e} + r_k \tag{6}$$

where p_k, q_k, r_k are considered as weights to be updated. The final output are summed together as

$$u = \sum_{k=1}^{M} f_k \tag{7}$$

Weights are updated by the backpropagation algorithm.

3. EXPERIMENTAL RESULTS

Experimental setup is shown in Fig. 5. A 100g weight is attached to the front of the top. The hardware of the whole system includes a DSP(TMS28335), an ARS sensor, motors, and driving circuits. Both control schemes are used for the angle and position without the heading angle.

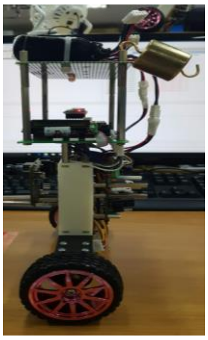


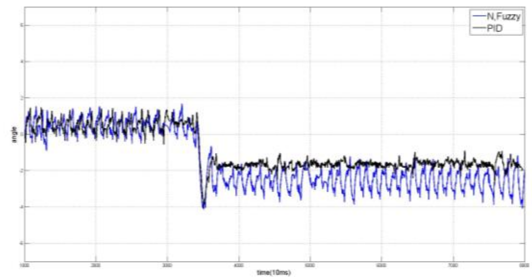
Fig. 5 Two-wheel robot with a 100g weight

To evaluate the effectiveness of the proposed architecture, performances of the neuro-fuzzy based controller and the PID controller are compared. Controller gains used are listed in Table 1.

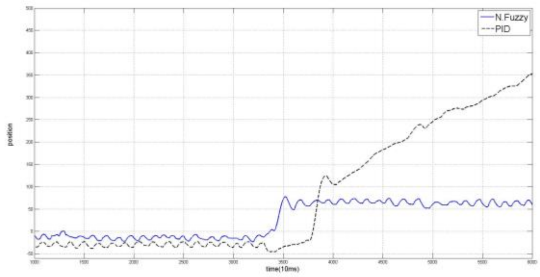
Fig. 6 shows the control performances. We see that the robot of the PID control scheme keeps moving toward one direction when a weight is added while the robot stays in the neuro-fuzzy control scheme.

Table 1. PID gains

	Kp = p0	Kd = q0	Ki = r0
Angle	1200	8	0.005
Position	20	60	0.005



(a) angle



(b) position

Fig. 6 Balancing results

4. CONCLUSIONS

Balancing control performances of a two-wheel robot have been tested by PID control and neuro-fuzzy control schemes. When a weight is added, two control schemes maintained balance successfully, but error deviation of the neuro-fuzzy control scheme is smaller.

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