Research on neuron PID-controlled simple wind tunnel system

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Abstract. The motion of the object in the wind tunnel is irregular. In order to control it accurately, a simple device is designed. The table tennis is blown by fan, its position in wind tunnel is measured by ultrasonic module, and its motion is controlled by PID algorithm. In order to accurately control the position and orientation of table tennis in the wind tunnel, an improved adaptive PID control algorithm is used to generate PWM wave to control the wind force of the axial flow fan. The online adjustment of P, I and D parameters is realized to improve the adaptability of the system. The test results show that the table tennis can hover at any given position or move regularly through the self-adaptive PID adjustment and the automatic adjustment of online parameters.

1. System design
Firstly, the system scheme is designed, and stm32f103zet6 is selected as the main control to realize the motor control, ultrasonic module ranging and display driving. The motor drive adopts btn7971 [1-5]. The display unit adopts 1.44 inch LCD.

2. Hardware design

2.1. BTN7971 Motor drive circuit design
Figure 2 shows the motor drive. Btn7971 can control the operation of the axial flow fan. PC6 and PC7 output PWM wave with adjustable duty cycle to adjust the fan speed.

![System block diagram](image_url)
2.2. Ultrasonic ranging circuit design
Figure 3. Ultrasonic module can measure distance and output its measured value through serial port.
\[
D = H\_DATA \times 256 + L\_DATA
\]

![Ultrasonic module diagram](image)

**Figure 2.** Motor drive circuit of BTN7971.

2.3. Display circuit design
Figure 4 shows the LCD driving circuit. SPI interface is used to connect with STM32[6-7].

![LCD interface diagram](image)

**Figure 4.** Shows the circuit interface design.

3. Adaptive PID controller design
3.1. Neuron PID controller design
The neuron PID controller is shown in Figure 5. In the figure, \(X_i(t)\) (I=1,2,3) is the input of neurons, \(U(t)\) is the output, and \(W_i(I=1,2,3)\) is the weight of the corresponding input \(X_i(t)\).
In order to match the neuron output with the PID control, the \( P \), \( I \) and \( D \) differential forms corresponding to the neuron input are given, as shown in Formula (1).

\[
\begin{align*}
X_i(t) &= e(t) \\
X_2(t) &= \sum_{i=0}^{n} e(i) \\
X_3(t) &= e(t) - e(t - 1)
\end{align*}
\]

In formula (1), \( X_i(t) \) (\( i = 1, 2, 3 \)) is the input corresponding to the neuron at time \( T \). \( E_i(t) \) (\( i = 1, 2, 3 \)) is the error value, which is described in detail in Fig. 6 \([7,9]\). In this way, the output \( U(t) \) of the neuron is shown in formula (2).

\[
U(t) = X_1(t) \times W_1 + X_2(t) \times W_2 + X_3(t) \times W_3
\]

3.2. Adaptive PID controller design

The adaptive PID controller is shown in Figure 6. In the figure, \( Y_r(t) \) is the output value set by the controller, \( y(t) \) is the actual output value of the controller, and \( E(t) \) is the error value, which is calculated by formula (3). The input to the neuron is then converted by formula (1) \( X_i(t)(i = 1, 2, 3) \).

\[
e(t) = y_r(t) - y(t)
\]

In order to make the system converge faster, supervised Hebb learning algorithm is adopted. The calculation formula is as follows:

\[
\Delta w_{ij} = w_{ij}(n+1) - w_{ij}(n) = \eta e(t)x_j
\]

In formula (4), \( W_{ij}(n+1) \) is the weight of neuron node \( I \) and \( J \) at the moment of \( (n+1) \), \( W_{ij}(n) \) is the weight of neuron node \( I \) and \( J \) at the moment of \( N \). \( Y_i \) is the output of neuron \( I \).

When the learning algorithm is adopted, the PID control weight \( W_i(I = 1, 2, 3) \) should be modified online. In the fixed time, weights \( W_i \) and error \( e(t) \), first order difference \( \Delta e(t) \), \( e(t - 2) \) have a
relationship, but through the study found that with \(e(t^2)\), so to improve the calculation speed, speed up the learning. The improved weight algorithm is as follows:

\[
\begin{align*}
    w_i(t) &= w_i(t-1) + \eta_p z(t) u(t) [e(t) + \Delta e(t)] \\
    w_2(t) &= w_2(t-1) + \eta_i z(t) u(t) [e(t) + \Delta e(t)] \\
    w_3(t) &= w_3(t-1) + \eta_d z(t) u(t) [e(t) + \Delta e(t)]
\end{align*}
\]

(5)

Formula (5), \(\eta_P, \eta_I, \eta_D\) learning coefficient, \(z(t) = e(t), \Delta e(t) = e(t) - e(t-1)\).

After normalization, the weight is:

\[
    w_i = \frac{w_i(k)}{\sum_{i=1}^{3} |w_i(k)|}
\]

(6)

The output of PID controller is:

\[
    u(t) = u(t) + k \sum_{i=1}^{3} w_i(t) x_i(t)
\]

(7)

In formula (7), \(x1(t)=e(t), x2(t)=e(t)-e(t-1), x3(t)=e(t)-2e(t-1)-e(t-2)\).

It can be seen from the algorithm that the initial weight has little influence on the output, which is mainly related to the learning rate \(K\). Through iteration of the algorithm, the initial weight approaches the optimal weight. When \(k\) is small, learning is slower, and when \(K\) is large, learning is faster. The output of \(U(t)\), namely PWM wave, controls the wind force of an axial flow fan.

4. Test

The wind tunnel consists of a circular pipe, a connecting part and an axial flow wind mechanism. The round pipe is placed vertically, with a length of 40cm, an inner diameter of 5cm and a diameter of 4cm. Table tennis balls can move up and down in the pipe. Ultrasonic ranging module is fixed on the fan.

During the test, after debugging the hardware and writing the program, the data is collected every 10ms, that is, the value of \(T\) is 10ms. \(Y_r(t)\) is the set ping-pong position value, \(y(t)\) is the actual position value measured by ultrasonic sensor, and \(E(t)\) is the error value of the two.

The parameters of \(P, I\) and \(D\) were determined by a large number of experiments and empirical values \(\eta_P, \eta_I, \eta_D\) as described below.

4.1. First adjust the parameter \(\eta_P\)

Direct given PWM, so that PWM can reach the set value, preferably more than 20%. Then, the parameter \(\eta_P\) is determined according to this value. Then, it is adjusted appropriately until the system does not oscillate. After many experiments, the \(\eta_P = 0.21\). The waveform is shown in Figure 7.

4.2. Adjust the eta \(\eta D\)

The function of \(\eta D\) is mainly to eliminate the shock, the greater the value, the better the effect. After many times of comparison, we get a \(\eta D = 0.35\).

The waveform shown in FIG. 9 shows that the vibration has been effectively eliminated.

4.3. The regulation of eta \(\eta I\)

If the system can enter the steady state after adjusting the \(P\) and \(\eta D\), but cannot reach the given value, add the \(I\) to eliminate the static error. The initial value of \(I\) is small, starting from 0.01 and gradually increasing. Meanwhile, when adjusting the \(\eta I\), the \(\eta P\) should be decreased and the \(\eta D\) should be increased. To stabilize the system at a given value.
Comparing Fig. 7 to Fig. 9, we can see that when determining the ηP, the curve has two waves; after adding a bit of ηD, the shock gradually disappeared. After ηI is added, the static error is eliminated, and the curve has become relatively perfect.
After the fixed-point debugging is completed, each parameter is basically determined. The set point can then be gradually increased or decreased so that the ping-pong ball can be played back and forth in the wind tunnel. If there is a deviation, it only needs to modify the P, I, and D slightly.

5. Conclusions
In this paper, a simple wind tunnel model is built by using BTN7971 to drive the axial flow fan to generate wind force, and by Ultrasonic ranging to determine the current position of the ping-pong ball. The parameters of $\eta_P$, $\eta_I$, $\eta_D$ were determined through a lot of experiments, and the online adjustment of P, I and D parameters was realized, which achieved the desired goal. The system has the advantages as below: fast response speed, high precision and automatic adjustment.

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