The study on Design and Algorithm of Robot Control System

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Abstract. The self-balancing robot sensor characteristics, proposed indirect Kalman filter algorithm based on a gyroscope and accelerometer data fusion, optimal inclination and angular velocity estimates. The steering system is decoupled into two subsystems forward. For forward subsystem has strong nonlinear, demonstrated the feasibility of the application of nonlinear systems based on approximate linearization, exact linearization and intelligent control of the control strategy.

Introduction

And the inverted pendulum systems, self-balancing robot not only required maintaining a balance, you must also achieve the desired movement. The most common way is to allow the movement of the robot at a given forward speed, if the need to do more complex movement (e.g., track the desired trajectory) can be given by the controller to achieve a speed corresponding to the instruction sequence. Due to the special nature of the structure, must make the robot speed servo controller on the basis of maintaining homeostasis, which is the difficulty of the subject. Because the goal of self-balancing robot applications is very broad, it may encounter unexpected complex environments, such as the road may not be smooth, there is a collision or interference by the wind.

Decoupling structure determination and control system

Applied to the left and right wheel motor control voltage, drive around the wheel movement, the robot will be able to achieve progress and steering. The forward speed of the robot speed is half the sum of two rounds, and the steering speed is directly proportional to the speed difference between the two rounds. Balance the subsystem to the forward advance speed and the vehicle body inclination angular velocity of the state vector, two half the sum of the motor voltage is input, the system can be obtained by the equation (1) is described.

\[
\begin{bmatrix}
  x_1 \\
  x_2 \\
  x_3 \\
  x_4
\end{bmatrix} = \begin{bmatrix}
  (a_x + a_y \cos x_2) x_1 + a_y \sin x_2 \\
  (b_x + b_y \cos x_2) x_1 - b_y \sin x_2 \\
  0 \\
  (c_y + c_x \cos x_2) x_1 - c_x \sin x_2
\end{bmatrix} \begin{bmatrix}
  1 - d_x \cos x_2 \\
  1 - d_y \cos x_2 \\
  u
\end{bmatrix}
\]

The steering angle of the subsystem to the state vector of the angular velocity \( \omega \), the voltage difference between the two motors half of input, the system can (2) described by the formula.

\[
\bar{x}_4 = -c_1 \bar{x}_4 + c_2 u
\]

After decoupling, respectively, can be designed for each of the two sub-controllers, the controller will calculate the balance of the forward advance according to a task \( u \), the steering controller will be solved according to the steering requirements of the conjugate value of \( u \), and finally by the following formula the control voltage then obtained about the motor.

Control Simulation

According to fuzzy adaptive algorithm design, simulation results are given under this algorithm. Figure 1 shows the case when the robot is in the initial state \([0 \ 1.5 \ 0]\) to return it to the controller is still successful balance, an excellent balance of properties. Figure 2 is a reference input is \( r = 1 \) in response to the forward speed of the robot, the robot tracking precision, fast response.
When the reference input is a sinusoidal signal, Figure 3 shows the output of the reference model, and Figure 4 for the speed of the output response curve. The simulation results show the effectiveness of FMRLC, the controller has finished the control tasks. In order to verify FMRLC adaptive function, in other parameters unchanged, so the system by $w = [0.2 \ 0 \ 0.1]^T$ of disturbance, the robot body mass becomes 3kg.

According to the environmental adaptability, a new study based on dynamic focusing fuzzy model reference learning control, under the control of the robot can adapt to the changing role of the parameters and the environment itself, and has a good balance of performance, high accuracy and robustness advantages. Control algorithms are simulated by MATLAB and Simulink, verify the correctness and validity of the design.

**Tracking simulation**
Figure 6 is a result of the robot tracing a straight line of $y = x + 5$, a) in the trajectory of the robot coordinate plane, b) shows the convergence of the state vector. The results show that the robot can accurately track lines, circles, and other trace curve, error convergence fast movement is very flexible, adaptable terrain.

![Figure 6 Line tracking of two-wheeled mobile robot](image)

**a) Tracking straight line $y = x + 5$  b). PE state vector changes**

![Figure 7 Circle tracking of two-wheeled mobile robot](image)

![Figure 8 Sine wave tracking of two-wheeled mobile robot](image)

Figure 7 and Figure 8 shows the two self-balancing robot trajectory tracking more complex capabilities. The simulation demonstrates the validity of the method.

**Experimental study of the system**

In order to adjust the parameters and verify the validity of the Kalman filter is a Kalman filter, the Kalman filter filtering the test platform to complete the experiment: the sensor module is connected to a potentiometer variable knob, rotation sensor within a certain range, the inclination obtained by a potential meter true value, and storing the angle and the angular velocity measurements accelerometers and gyroscopes obtained. Noise covariance matrices $Q$ and $R$ obtained through several experiments $Q = [0.05 0; 0 0.01]$; $R = [0.05]$; experimental results are shown in Fig.9.

![Figure 9 Comparison between estimated angle and true angle](image)

**Fig.9 Comparison between estimated angle and true angle**

Seen from Figure 9, the Kalman filter (up to about 3 degrees) and dip in the initial stages when the error is greater the larger the following reasons.

![Figure 10 Balance experiment without load](image)

![Figure 11 Balance experiment with load](image)

**Fig.10 Balance experiment without load  Fig.11 Balance experiment with load**

When seen from Figure 10, the robot from the load, the initial angle is about 12 degrees; after 0.5 seconds tend to balance the vibration of the rapid state of the body in a second range of tilt is no longer a large oscillation, the fuzzy verification model Reference learning Controller has a strong balance. Figure 11 shows the robot loads the quality of 0.4kg, and because of the presence of the load,
the robot body weight increases, shifting the center of mass, the robot can achieve balance control through learning.

Fig. 12 Robust experiment

Seen from Figure 12, the robot suddenly imposed by external forces under external force, within 0.6 seconds of you can quickly return to equilibrium, showed linear quadratic optimal tracking controller is real good, good for the inhibitory effect of external interference to verify the ability to suppress interference robustness.

Summary

In this paper, two-wheeled self-balancing robot as research object, first introduced the two-wheeled self-balancing robot test platform, and then for the sensor data fusion based on indirect Kalman filter, balance control, robustness and speed tracking experiments conducted research on mathematical model, sensor data processing, and speed controller, position controller design, carried out research. The experimental data have been analyzed experimental results verify the correctness and validity of theoretical research.

References