Fuzzy logic position control of the mini-linear driver*

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Abstract In order to overcome the limitations of the end clamps of traditional robot, multifingered dextrous robot hands have been well developed since the last decade. A new fuzzy logic control structure is presented in this article, which is for the position control of the mini-linear driver used in driving the joints of the dextrous robot hands. This method is proved to be effective in simulations and practices, and especially useful when the external disturbance varies in a large range.

Keywords: multifingered dextrous hand, fuzzy control, linear driver.

In order to realize the tasks such as conveying, jointing, spray-painting and so on, the simple clamps of traditional robots are used to nip the workpieces. This simple clamps have lots of shortcomings such as lack of agility, the limited nipping suitability, a low efficiency and lack of precise force controlling

Multifingered dextrous robot hands (dextrous hands) have been used to solve these problems. It makes the robot much more agile and universal. The original dextrous hands came out at the beginning of the 1980’s. The four-finger UTAH/MIT hand and three-finger SALISBURY hand are typical examples[1][2]. A common character of those early dextrous hands is that the mechanisms of fingers are separated from their driving components, and long cords are usually needed to connect them.

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The disadvantages of this structure include relatively large sizes, and the slow dynamic response of the fingers.

The Institute of Robotics and System Dynamics of German Aerospace Center (DLR) developed a mini-linear driver named ‘artificial muscle’, which is used in the four-finger DLR hand[3]. Its primary parts included a brushless DC motor and miniature planet axises. The spindle of the driver moved along its axes. The diameter of the driver was only 21mm, and the highest load reached 150N. Therefore it was very suitable to drive the joints of robot hands.

Based on this model, we developed a mini-linear driver with even smaller size and more output force. Its diameter is 19mm, and the highest load is 200N.

1  Model of linear driver

Mechanical structure of the linear driver is shown in Fig.1, which includes some pivotal parts, i.e. 1-spindle, 6-motor coil, 8-planet wheels.

\[
J_m \ddot{\theta}_m(t) + B_m \dot{\theta}_m(t) + T_r + T_s + n \tau_L = \tau_m
\]

If the inductance of the motor is ignored, the torque equation of the motor can be simplified as:

\[
\tau_m = K_t I_m
\]
where $\theta_m$ is the angle of motor rotation, $J_m$ and $B_m$ are the total moment of inertia and the damp coefficient respectively, $T_f$ is the friction force, $T_g$ the gravity, $n\tau_L$ the external force acted on the linear driver, $\tau_m$ the output moment of the motor, $I_m$ the drive electric current of the motor, and $K_l$ the moment coefficient.

Define the deceleration rate of the linear driver $n$ by the output linear displacement divided by the angle of motor rotation with unit m/rad,

$$n = 0.75 \cdot \frac{l}{2\pi} \quad (3)$$

where $l$ is the spiral distance of the spindle.

Suppose $x$ is the displacement of linear driver,

$$x = n \cdot \theta_m \quad (4)$$

Therefore, the mathematical model for the linear driver can be expressed as

$$J_e \ddot{x} + B_e \dot{x} + T_L = T \quad (5)$$

where $J_e = J_m/n$ and $B_e = B_m/n$ are the equivalent inertia and the damp coefficient of the linear driver respectively.

2 Fuzzy logic controller

In order to smoothen the movement of the robot fingers, the position control of linear driver should have no overshoot and steady-state error. And the response rate must be consistent with the load changes. It is difficult to achieve the above object using the traditional control law because that the external disturbances vary in a large range. Therefore a fuzzy control law is applied in this article which realizes perfect controlling of the linear driver.

Fuzzy logic control is an intelligent control method, which reflects the human experience and strategy of controlling.
The subjection function and fuzzy reasoning rules are the elements of fuzzy controllers. A fuzzy reasoning rule named exact value method is adopted in this paper, which has the advantage of precision[4]. For the example of a fuzzy controller with two inputs and one output, the relationship between the inputs and output is shown in Fig. 2. This kind of controller is much more suitable for the control of nonlinear objects than using the conventional PID laws.[5]

Triangular subjection function is adopted for the input and output variables of the fuzzy controller. Optimization is performed according to Ref.[6]. It adjusts the discuss fields of the subjection functions of the inputs and output with three parameters, and searches for the most favorable values with simple shape method.

There are two kinds of basic fuzzy controllers position style and velocity style. The output of position style fuzzy controller is the control quantum, which has the merit of fast response and fine damp character and so on. But there exists steady-state error when the external disturbance is continuous. And the output of velocity style
Fuzzy controller is the increment of control quantum, which eliminates the steady-state error through integration action, but it is liable to surge. The two kinds of fuzzy controllers are combined in a parallel structure, which inherits the merit of both styles as shown in Fig. 3.

The load of mini-linear driver varies in a large range. For keeping the movement of the robot fingers smooth, the position control of linear driver should have no overshoot and steady-state error, and the response rate must be consistent while the load changes.

The velocity style fuzzy controller is applied to eliminate the steady-state error, but it influences the dynamic response unfavorably. For minimizing the bad effect, velocity style fuzzy controller is not acting until it approaches the steady state. And the gain of velocity style is far less than that of position style’s. Its output is shown in Fig. 4.

This fuzzy controller is designed and debuged in the simulation environment which is constructed by a computer. The Simulink of MATLAB software provides a powerful tool for the simulation. The parameters of fuzzy controller are adjusted according to Ref.[6], and the optimized controller achieves satisfactory result.

3 Result and analysis

We constructed a real time control system based on a Digital Signal Processing (DSP) board to verify the performance of the fuzzy controller. The core of the system is a TMS320C40 processor. The full-scale displacement of linear driver is 25mm, and
full load is 20kg. The control voltage of motor is -24V~24V. Control result with low load (1kg) is shown in Fig. 5. Control result with full load is shown in Fig.6. It is obvious that the control result is satisfactory for different load conditions. Because the static friction of linear driver changes with different load, the traditional PID law is not suitable for the control of it.

Fig. 5  Control result with low load.

Fig. 6  Control result with full load.
References


Fig. 1  The mechanical structure of linear driver (unit: mm)

Fig. 2  Output of position style fuzzy controller
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Fig. 3  Schematic diagram of the fuzzy controller

Fig. 4 Output of velocity style fuzzy controller
Fig. 5  Control result with low load (T is the sampling period)
Fig. 6  Control result with full load (T is the sampling period)