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Adaptive Fuzzy Sliding Mode Control Method for Vision-Based Food Packaging Line Robot Joint

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In the cold frozen food product packaging production line, as the products' geometric parameter is changing, so the manual work remains the main ways in today's food packaging production line, in order to enhance the degree of automation, this paper designed a control system of Vision-Based food packaging line with Adept robot and proposed the double adaptive fuzzy sliding mode control to investigate joint trajectory control of food packaging line robot. The simulation results indicate that the proposed double adaptive fuzzy sliding mode control method can effectively guide the joint trajectory and is much better than traditional sliding mode control.

1. Introduction

On the frozen food packaging line, control system generally delivers the unpacking products to the site without implementing accurate control of the products position. This makes most robots can`t be used in such productive process due to the robot off-line programming requires accurate modeling of the working environment.

Although simple and repetitive work it is, but the change of packing product geometric parameters in a certain range makes today's food packaging line still be a highly intensive labor work. How to bring the robot operating into food packaging line is a research has important application value. Its key technology is the introduction of external sensors which processing the information on the spot online , so as to control the robot.

sliding mode variable structure has a strong robust stability to the perturbation and external disturbances of system parameters, so it provides a good solution for complex system control problem. Many scholars integrated fuzzy logic system with sliding mode control and this method has become an effective solution to the nonlinear and uncertain dynamical systems control. It is also be used to ease the implementation difficulties of conventional sliding mode control which was confirmed(Choi and Kim(1997), Ha, Rye and Durrant-Whyte(1999), Kaynak, Erbatur and Ertugrul(2001), Tong and Li(2003), Chen and Chen(1998), Noroozi, Roopaei and Jahromi(2009), Roopaei, Sahraei and Lin(2010), Xiang and Chen(2011), Wang, Rad and Chan(2001), Akbarzadeh and Shahnazi.(2005), Bai et al.(2009), Liu, Liu and Jiang Jihai(2010), Lin, Mao and Cao Yunpu(2001), Hu and Zhou(1991), Zheng, Cheng and Gao(1995), TKIN(1992), Park and Teruo(1999), Carrasco et al.(1997)). Choi and Kim(1997), Ha, Rye and Durrant-Whyte(1999), Kaynak, Erbatur and Ertugrul(2001), Tong and Li(2003), Noroozi, Roopaei and Jahromi(2009), Roopaei, Sahraei and Lin(2010) designed different fuzzy sliding mode control methods applying them into different nonlinear system and the outcomes were positive. Wang, Rad and Chan(2001), Akbarzadeh and Shahnazi.(2005), Bai et al.(2009), Liu, Liu and Jiang Jihai(2010) combined adaptive algorithms with fuzzy sliding mode control to enhance robust stability and weaken the high frequency chattering phenomenon in the control signal.

This paper designed a control system of Vision-Based food packaging line with Adept robot and proposed the double adaptive fuzzy sliding mode control to investigate joint trajectory control of food packaging line robot. The simulation results indicate that the proposed double adaptive fuzzy sliding mode control method can effectively guide the joint trajectory and is much better than traditional sliding mode control.

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2. System design

Frozen food packaging line vision-based robot control system is shown in figure 1, which is composed of host workstation, the visual system and robot system. The system uses the robot to grab, localize the moving objects and placed them in position. Vision system consists of three parts, namely, the CCD camera, the coordinate converter and image processing software, including image processing algorithm for system to get information quickly and the initialized image equipment.

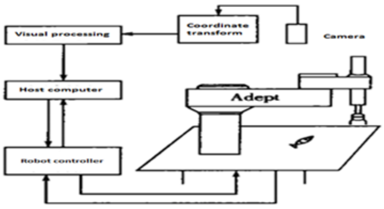

Figure 1: Vision-based robot control system for frozen food packaging line

After control task was determined, according on the visual-based algorithm and the robot posture, host computer will transmission data to the low-level robot system. The system will determine the location relationship between the finger and the actual grab objects based on images that CCD camera detected, and then the robot control algorithm is designed to adjust the position of the robot, so as to achieve the capture of objects.

3. Double adaptive fuzzy sliding mode control design

In recent years, the sliding mode control is widely used in motion control because of its merits in simple algorithm, strong robust stability, High Reliability, quick response and not sensitive to disturbance and parameter changes which was confirmed (Kaynak, Erbatur and Ertugrul(2001)). But because of time lag and spatial lag switch, inertia of system and uncertainty factors, after the state trajectory reaches sliding mode surface, the sliding mode variable structure control system is difficult to strictly sliding along the sliding mode to the balance, but crossing back and forth in the sliding mode surface on both sides, which resulting in a jitter. So it is easy to stimulate high-frequency unmodeled dynamic, so as to damage the system performance. In order to weaken the jitter of system, Tong and Li(2003) using the reaching law to weaken jitter problem produced by variable structure control. Chen and Chen(1998) designed a variable structure controller with a filter, effectively eliminate the chattering in the control. At the same time, adaptive control, neural network, fuzzy control and genetic algorithm (GA) and other advanced methods which was confirmed (Kaynak, Erbatur and Ertugrul(2001)) are applied to weaken the dithering phenomenon in the sliding mode variable structure control. This paper proposed the double adaptive fuzzy sliding mode control to investigate joint trajectory control of food packaging line robot.

3.1 control design

Consider the SISO nonlinear system

$$x = f\left(x,t\right) + g\left(x,t\right)u\left(t\right) + d\left(t\right) \tag{1}$$

Where $f\left(x,t\right)$ and $g\left(x,t\right)$ are unknown nonlinear functions, $g\left(x,t\right)>0$, $d\left(t\right)$ is the external disturb. Tracking error is

$$e\left(t\right) = x\left(t\right) - r\left(t\right) \tag{2}$$

Define the integral sliding mode surface as:

$$s\left(t\right) = x\left(t\right) - \int_0^t \left[r\left(t\right) - k_1 e\left(t\right) - k_2 e\left(t\right) - k_3 e\left(t\right)\right] d\left(t\right) \tag{3}$$

Where k_1, k_2 and k_3 are non-zero positive constants and can satisfy the Hurwitz stability criterion.

When the sliding mode control is in the ideal state, $s\left(t\right) = \dot{s}\left(t\right) = 0$,we have

$$s(t)=e(t)+k_1e(t)+k_2e(t)+k_3e(t)=0 \tag{4}$$

Suppose $f(x,t)$, $g(x,t)$ and $d(t)$ are known, from the equation(4), we can get the sliding mode control law as

$$\overset{*}{u}(t)=g(x,t)^{-1}\left[-f(x,t)-d(t)+r(t)-k_1e(t)-k_2e(t)-k_3e(t)\right] \tag{5}$$

In practical application, $f(x,t)$, $g(x,t)$ and $d(t)$ are all known, $\overset{*}{u}(t)$ can`t be obtained easily. This paper use the fuzzy system to approaching $\overset{*}{u}(t)$.Compared with traditional two input fuzzy controller, This article selects the switching function $s(t)$ as the input of fuzzy controller to constitute a single input fuzzy system, so largely reduced the number of fuzzy rules. The fuzzy rule of this controller is as follows:

Rule : If s is F_s^i, Then u is α_i. Where $i=1,2,\cdots,m,\ F_s^i$ and α_i are the fuzzy set.

Gravity method is adopted to improve the fuzzy system blurred, take α_i for adjustable parameter at the same time and get the output of the controller is:

$$u_{fz}(s,\alpha)=\alpha\xi^T \tag{6}$$

Where $\alpha=\left[\alpha_{1,}\alpha_2...\alpha_m\right]$, $\xi=[\xi_1,\xi_2...\xi_m]$, $\xi_i=\dfrac{\omega_i}{\sum_{i=1}^{m}\omega_i}$.

According to the fuzzy approximation theory, there is a optimal fuzzy system to approach $\overset{*}{u}(t)$, we have

$$\overset{*}{u}(t)=u_{fz}\left(s,\alpha^*\right)+\varepsilon=\alpha^*\xi+\varepsilon \tag{7}$$

The ε is the approximation error of fuzzy system, satisfy | ε | < E |.

Use $u_{fz}(s,\hat{\alpha})$ to approaching $\overset{*}{u}(t)$,then $u_{fz}(s,\hat{\alpha})=\hat{\alpha}\xi^T$, where $\hat{\alpha}$ is the estimated value of α^*,define $\tilde{\alpha}=\hat{\alpha}-\alpha^*$.From equation (27), we can get

$$u_{fz}=\hat{u}_{fz}-u^*=\hat{u}_{fz}-u_{fz}^*-\varepsilon=\alpha\xi-\varepsilon \tag{8}$$

To compensate for the fuzzy approximation error between $u_{fz}(s,\hat{\alpha})$ and $\overset{*}{u}(t)$,we introduced the switching control law u_{vs} ,now total control law expressed as

$$u_t=u_{fz}+u_{vz} \tag{9}$$

The system structure of double adaptive fuzzy sliding mode control is shown in Fig.2.

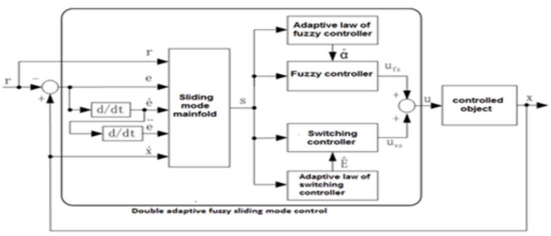

Figure 2: Double adaptive fuzzy sliding mode control system

3.2 self-adaptive control algorithm design
From equation (3), we have

$$s(t)=e(t)+k_1e(t)+k_2e(t)+k_3e(t) \tag{10}$$

then equation(5)can be treated as

$$u^*(t)=g(x,t)^{-1}\left[g(x,t)u(t)-\dot{s}(t)\right] \tag{11}$$

From equation(9)and (11),we can obtain

$$\hat{s}(t)=g(x,t)\left[u(t)-\overset{*}{u}\right]=g(x,t)\left[u_{fz}+u_{vz}-\overset{*}{u}(t)\right] \tag{12}$$

when switching controller, the switching gain is difficult to determine, it is often determined by experience in the actual control. If the switch gain is too large, then it will produce larger chattering. If the switch gain is too small, the control system will be unstable.
Define Lyapunov function as

$$V(t)=\frac{1}{2}s^2(t)+\frac{g(x,t)}{2\eta_1}\alpha\alpha^T+\frac{g(x,t)}{2\eta_2}E^2 \tag{13}$$

where $\alpha=\hat{\alpha}-\alpha^*$, $E(t)=\hat{E}(t)-E$. η_1 and η_2 are positive constants, $\hat{E}(t)$ is the estimated switching gain.
The adaptive law and switch control are used to achieve $V(t)\leq 0$,

$$\alpha=\hat{\alpha}=-\eta_1 s(t)\xi \tag{14}$$

$$E=\hat{E}(t)=\eta_2\left|s(t)\right| \tag{15}$$

$$u_{vz}=-\hat{E}(t)\operatorname{sgn}\left(s(t)\right) \tag{16}$$

Then we have

$$V(t)=\frac{1}{2}s^2(t)+\frac{g(x,t)}{2\eta_1}\alpha\alpha^T+\frac{g(x,t)}{2\eta_2}E^2 \tag{17}$$

$$\begin{aligned}
V(t)&=s(t)s(t)+g(x,t)\alpha\alpha^T/\eta_1+g(x,t)EE/\eta_2\\
&=s(t)g(x,t)[u_{fz}+u_{vs}-u^*(t)]+\ g(x,t)\alpha\alpha^T/\eta_1+g(x,t)EE/\eta_2\\
&=s(t)g(x,t)[\alpha\xi-\varepsilon+u_{vs}]+g(x,t)\alpha\alpha^T/\eta_1+g(x,t)EE/\eta_2\\
&=s(t)g(x,t)(u_{vs}-\varepsilon)+g(x,t)\alpha(s(t)\xi+\alpha^T/\eta_1)+\ g(x,t)EE/\eta_2\\
&=-\hat{E}(t)\,|\,s(t)\,|\,g(x,t)-\varepsilon s(t)g(x,t)+g(x,t)(\hat{E}(t)-E)E/\eta_2\\
&=-\hat{E}(t)\,|\,s(t)\,|\,g(x,t)-\varepsilon s(t)g(x,t)+(\hat{E}(t)-E)\,|\,s(t)\,|\,g(x,t)\\
&=-\varepsilon s(t)g(x,t)-E\,|\,s(t)\,|\,g(x,t)\ =-(E-|\,\varepsilon\,|)\,|\,s(t)\,|\,g(x,t)\leq 0
\end{aligned} \tag{18}$$

4. Numerical simulation study

In order to verify the effectiveness of the proposed algorithm in this paper, a joint of Adept was take as the research object to run a simulation. Assume joint servo system`s transfer function is as follows:

$$G(s)=\frac{133}{s^2+25s} \tag{19}$$

in the Simulation, sampling period is set to 0.001 s, Fuzzy controller and switch controller parameters respectively take η1 = 200, η2 = 1, the initial value of $\hat{\alpha}$ and $\hat{E}$ are 0.1.7 membership functions are used to approaching $u^*(t)$ in the sliding mode control. Under the condition of same parameter variations and external load, respectively, we run the simulation of the hydraulic servo system, using the proposed adaptive fuzzy sliding mode control and the conventional proportional – integral- differential (PID) control. The results are shown in Fig3,Fig4 and Fig.5.
The proposed double adaptive fuzzy sliding mode control can ensure the good tracking effect (Fig. 3 a), and converge within the limited time (4 s). The tracking error is affected by the system initial state from 0.2 mm rapidly reduced to zero(Fig. 4 a) and keep near the zero line. The maximum stable error is only 3μm. And the simulation results of conventional PID control method show that the conventional PID control has a good real-time tracking (Fig.3 b), but the tracking error is significantly larger, steady-state error is 15μm. The steady-state error is five times compared with the double adaptive fuzzy sliding mode control, and has obvious oscillation (Fig.4 b).

(a) Double adaptive fuzzy sliding mode control *(b) PID control*

Figure 3: Position trailing

(a) double adaptive fuzzy sliding mode control *(b) PID control*

Figure 4: tracking error

5. Conclusions

(1)Designed a food packaging production line control system based on visual and Adept robot, the adaptive fuzzy sliding mode control is put forward. The integrating the fuzzy control, sliding mode control and adaptive control gives full play to their respective advantages. This method don`t rely on the accurate mathematical model which is the traditional control system needed for, and can effectively track changing signal. It has strong invariance to bounded disturbance and parameter perturbation which is superior to the conventional PID control.

(2)The double adaptive fuzzy sliding mode control used adaptive fuzzy controller which can adjust parameters online based on fuzzy rules, it can smooth the discontinuous control and achieve the goal of weaken chattering. Simulation examples show that this system has a good dynamic response performance, high steady state accuracy and strong robustness to the parameter perturbation and load changes.

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