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Research Article

Study of Food Packaging Production Line Shunt-wound Pick and Place Mechanical Arm Track Sliding-mode Control based on Self-adaption Exponential Reaching Law

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Abstract: Shunt-wound pick and place robot was used in packing industry and it had mechanical closed-loop construction. This kind of robots was used widely in production lines to transport subjects point-to-point. Sliding-mode control was used in controlling the shunt-wound pick and place robots in this study. Based on the short of reaching law control arithmetic, a kind of self-adapting reaching law sliding-mode control arithmetic was raised. The simulation result indicated: the arithmetic which was raised in this study could overcome the shake in traditional reaching law control arithmetic.

Keywords: Food packaging, self-adaption exponential reaching law, sliding-mode control

INTRODUCTION

The traditional dried bean curd packing production lines was always choosed stretch film packaging machines to packing (Miaochao *et al.*, 2014). The shaping room was used to heat treating and vacuumizing plastic film. Then the plastic films like bowls. Feeding areas was put the artifactitous dried bean curds into the plastic cases according to certain laws. Then the plastic cases were filmed and vacuumized by the filming system and vacuum air-removed system system. Finally the transverse and longitudinal cutting knife cut the plastic cases to get items. In general, one production line needs four workers working in the same time, because of the increasing of labour charges and the need of advancing the safety of food hygiene and realizing full automation in production lines, the work in feeding areas are finished by pick and place robots.

Sliding mode variable structure control arithmetic was used in controlling the shunt-wound pick and place robots in this study. Sliding mode variable structure was a kind of special non-linear control in essence (Jue-ping *et al*., 2015). Its nonlinear characteristic was reflected in the discontinuity of controlling. This control strategy was different from others because of the construction of its system was not fixed. The construction can changed purposefully according to the status of system in dynamical process, so the system must work according to the scheduled motion trail. The sliding mode can be designed and it has not connection with plant parameters and shark, so variable structure controlling can respond quickly and are not sensitive to the change of plant parameters and shark, has no need of online identification. The short of this method is when the state trajectory is reaching sliding mode surface, it is difficult to turn towards balance point along the sliding mode surface strictly. It crosses back and forth in the sliding mode surface on both sides, so shark generates.

Weibing (1996) proposed a method which can remove jitter in variable structure controlling system. Taking exponential reaching law $s = -\varepsilon \cdot \text{sgn}\ s - k \cdot s$ for example, by adjusting the reaching law parameters k and c, the dynamic quality when sliding mode arrival process can be ensured, in the same time, the high frequency chattering of control signal can be weakened (Xiuying and Tiezhong, 2005). But the bigger ε will result in shark. In study, a control strategy was proposed which contact discrete reaching law with equivalent control, discrete reaching law only worked at approaching stage, when the state of system reaches the sliding-mode stage, the disperse equivalent control works. So this strategy not only ensured the good quality of reaching mode, but also reduced quasi-sliding mode delt, eliminated shark. In study (Jiang *et al.*, 2002), fuzzy control was used in exponential reaching law, by analyzing the fuzzy relation between switch function and exponential reaching law, using fuzzy law adjust reaching law parameters, therein the absolute value of witch function was used as the input of fuzzy law, the coefficient of exponential reaching law k and ε was used and the output of fuzzy law. The quality of sliding-mode get further improved and the high frequency chattering of system was eliminated.

This study analyzes why approaching coefficient causes shark when the exponential reaching law was used in disperse system, proposed a self-adaption reaching law sliding-mode control algorithm based on approaching coefficient ε adjust itself. Then simulation experiments were did based on self-adaption approaching law sliding mode variable structure control algorithm and traditional approaching law sliding mode variable structure control algorithm by using Matlab/Simulink. The results indicated that the self-adaption approaching law sliding mode variable structure control algorithm which was proposed in this study can reduced the shark problem in traditional algorithm.

MATERIALS AND METHODS

Shunt-wound pick and place mechanical arm system: The Shunt-wound pick and place robot which was studied in this study looks like Fig. 1 (Shuanghe *et al.*, 2001), the driven arm contact with driving arm and moving stage by hooke joint. It is composed of three full symmetrical motion branched-chain. Each branched-chain drives one driving arm with rotation joint by one actuating motor. Both driving arm drives driven arm and driven arm drive moving stage by hooke joint, cupala was installed on moving stage so that workpiece can be sucked up and putted down. Driven arm uses parallel quadrangle organization.

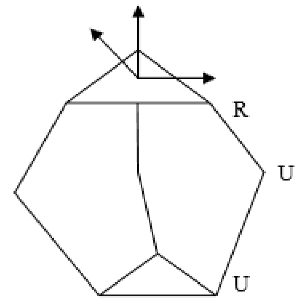

Fig. 1: The model of Shunt-wound pick and place mechanical arm system

Designing and shark analyzing of sliding-mode controller:

Design sliding-mode controller: Thinking about discrete system as follow:

$$x(k+1) = Ax(k) + Bu(k) \tag{1}$$

In this system, design sliding-mode controller as follow:

$$u(k) = \begin{cases} u^{+}(x(k)), s(x(k)) > 0 \\ u^{-}(x(k)), s(x(k)) < 0 \end{cases} \tag{2}$$

In which, $s(x(k))$ is sliding-mode surface.

According to the exponential reaching law proposed in literature (Liu, 2007):

$$s(k+1) = (1 - qT)s(k) - \varepsilon T \operatorname{sgn} s(k) \tag{3}$$

Because of $s(k+1) = c^T x(k+1)$, so:

$$\begin{aligned} s(k+1) &= c^T x(k+1) = c^T (Ax(k) + Bu(k)) \\ &= c^T Ax(k) + c^T Bu(k) \end{aligned} \tag{4}$$

Then:

$$\begin{aligned} &c^T Ax(k) + c^T Bu(k) \\ &= (1 - qT)s(k) - \varepsilon T \operatorname{sgn} s(k) \end{aligned} \tag{5}$$

So control:

$$\begin{aligned} u(k) &= (c^T B)^{-1}[(1-qT)s(k) - \varepsilon T \operatorname{sgn} s(k) - c^T Ax(k) \\ &= -(c^T B)^{-1}[(qT-1)s(k) + \varepsilon T \operatorname{sgn} s(k) + c^T Ax(k) \end{aligned} \tag{6}$$

Analyze sharking: On the basis of Design sliding-mode controller, the sliding-mode surface is:

$$s(k+1) = (1 - qT)s(k) - \varepsilon T \operatorname{sgn} s(k) \tag{7}$$

So, form 7 can be rewrote as:

$$\begin{aligned} s(k+1) &= (1-qT)s(k) - \varepsilon T \frac{s(k)}{|s(k)|} \\ &= ((1-qT) - \varepsilon T \frac{1}{|s(k)|})s(k) \\ &= ps(k) \end{aligned} \tag{8}$$

From form 8, we can indicate:

$$|p| = \frac{|s(k+1)|}{|s(k)|},\ p = 1 - qT - \frac{\varepsilon T}{|s(k)|} \tag{9}$$

Obviously, $p < 1$.

To decrease the sharking exist in sliding-mode control further, in this study sharking exist in this algorithm was analyzed, an improved method has been proposed:

- When $|s(k)| > \frac{\varepsilon T}{2-qT}$, put it into form (9), so:

$$p > 1 - qT - \frac{\varepsilon T}{\frac{\varepsilon T}{2-qT}} = -1 \tag{10}$$

So,

$$-1 < p < 1, |p| = \frac{|s(k+1)|}{|s(k)|} < 1$$

- When $|s(k)| < \frac{\varepsilon T}{2-qT}$, put it into form (9), so:

$$p < 1 - qT - \frac{\varepsilon T}{\frac{\varepsilon T}{2-qT}} = -1 \tag{11}$$

So,

$$|p| = \frac{|s(k+1)|}{|s(k)|} > 1$$

- When $|s(k)| > \frac{\varepsilon T}{2-qT}$, put it into form (9), so:

$$p = 1 - qT - \frac{\varepsilon T}{\frac{\varepsilon T}{2-qT}} = -1 \tag{12}$$

So $|p| = \frac{|s(k+1)|}{|s(k)|} = 1$ at this time, s(k) is oscillatory conditions.

To ensure s(k) is always being degression status, must ensure that: $|s(k)| > \frac{\varepsilon T}{2-qT}$ in the process of sliding-mode control, absolute value of sliding-mode surface $|s(k)|$ is infinite approaching $\frac{\varepsilon T}{2-qT}$.

when $|s(k)| = \frac{\varepsilon T}{2-qT}$, system becomes shark. To arbitrary $|s(0)| \neq 0$, $k \to \infty$, $|s(k)| \to \frac{\varepsilon T}{2-qT}$.

And when $|s(k)| = \frac{\varepsilon T}{2-qT}$.

There is: $s(k+1) = -s(k)$.

So when $k \to \infty$, the amplitude of oscillation of sliding-mode is:

$$h = \frac{\varepsilon T}{2-qT} \tag{13}$$

From (13), we can indicate that, for sliding-mode control, its amplitude mainly influenced by ε, T, q. So, as long as these parameters can be controlled reasonable, the control effect can be better.

Self-adaption sliding-mode controller:

Design controller: From last paragraph, when $|s(k)| > \frac{\varepsilon T}{2-qT}$, s(k) is decreasing. ε is very important. So,

$$\varepsilon < \frac{1}{T}(2-Tq)|s(k)| \tag{14}$$

To make control law easier, make:

$$T < \frac{4}{1+2q} \tag{15}$$

On the basis of (14) and (15), make:

$$\varepsilon = \frac{1}{2}|s(k)| \tag{16}$$

So form (7) can be rewrote as:

$$s(k+1) = (1-qT)s(k) - \frac{1}{2}|s(k)|T \operatorname{sgn} s(k) \tag{17}$$

$$s(k) = c^T E = c^T(R(x) - x(k)) \tag{18}$$

So:

$$s(k+1) = c^T E = c^T(R(x+1) - x(k+1)) \tag{19}$$

In that way:

$$\begin{aligned} & c^T(R(x+1) - Ax(k) + Bu(k)) \\ & = (1-qT)s(k) - \frac{1}{2}|s(k)|T \operatorname{sgn} s(k) \end{aligned} \tag{20}$$

Finally, the control law based on self-adaption sliding-mode control is:

$$\begin{aligned} & u(k) = (c^T B)^{-1}(c^T R(k+1) + qTs(k) \\ & + \frac{1}{2}|s(k)|T \operatorname{sgn} s(k) - c^T Ax(k) - s(k)) \end{aligned} \tag{21}$$

Prove stability: Define Lyapunov function as:

$$V(k) = \frac{1}{2}s^2(k) \tag{22}$$

If conditions meet:

$$\Delta V(k) = s^2(k+1) - s^2(k) < 0 \tag{23}$$

According to form (18), there is:

$$\begin{aligned} & (s(k+1) - s(k)) \operatorname{sgn} s(k) \\ & = (-qTs(k) - \frac{1}{2}|s(k)|T \operatorname{sgn} s(k)) \operatorname{sgn} s(k) \\ & = -(q+0.5)T|s(k)| < 0 \end{aligned} \tag{24}$$

At the same time:

$$\begin{aligned} & (s(k+1) + s(k)) \operatorname{sgn} s(k) \\ & = ((2-qT)s(k) - \frac{1}{2}|s(k)|T \operatorname{sgn} s(k)) \operatorname{sgn} s(k) \\ & = (2 - qT - 0.5T)|s(k)| > 0 \end{aligned} \tag{25}$$

So $\Delta V(k) = s^2(k+1) - s^2(k) < 0$, the algorithm is stable.

RESULTS AND DISCUSSION

Digital simulation study: To verify effectiveness of the algorithmic proposed in this study, apply this algorithmic in shunt-wound pick and place robot track controlling of food packaging production line, simulation result showed in Fig. 2 and 3.

Figure 2 is the result of trajectory tracking based on traditional sliding-mode control, Fig. 3 is based on self-

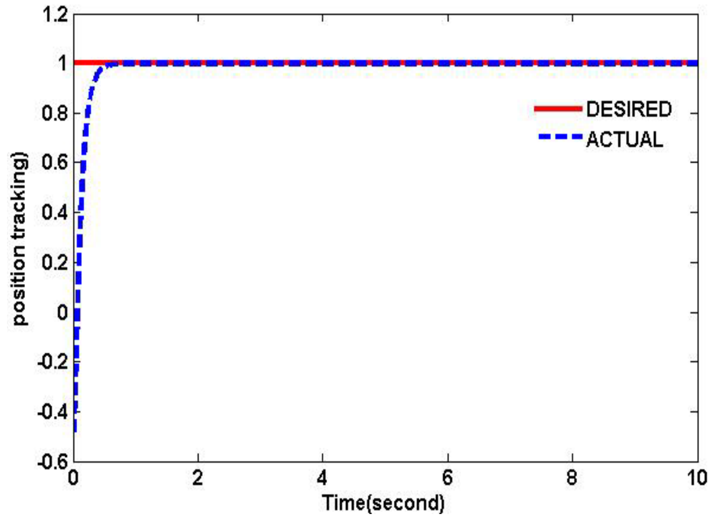

Fig. 2: Trajectory tracking of traditional sliding-mode control

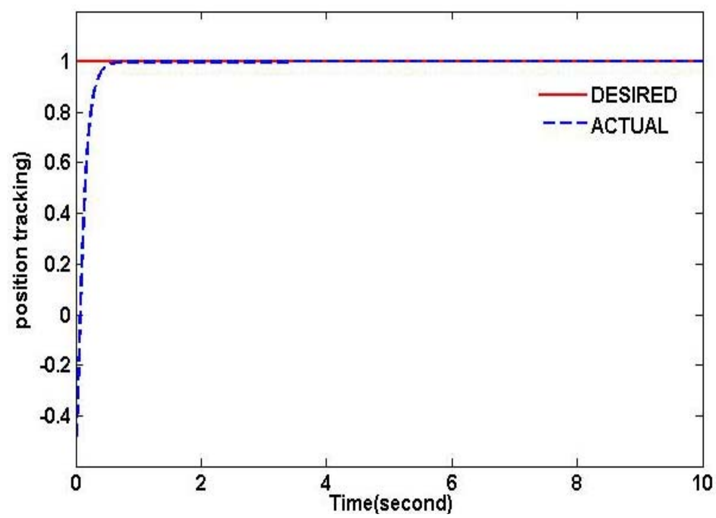

Fig. 3: Trajectory tracking of self-adaption sliding-mode control

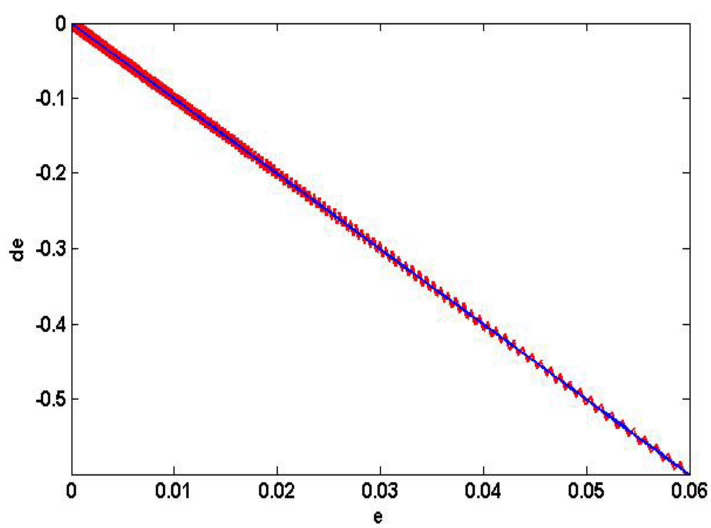

Fig. 4: Phase path of traditional sliding-mode control

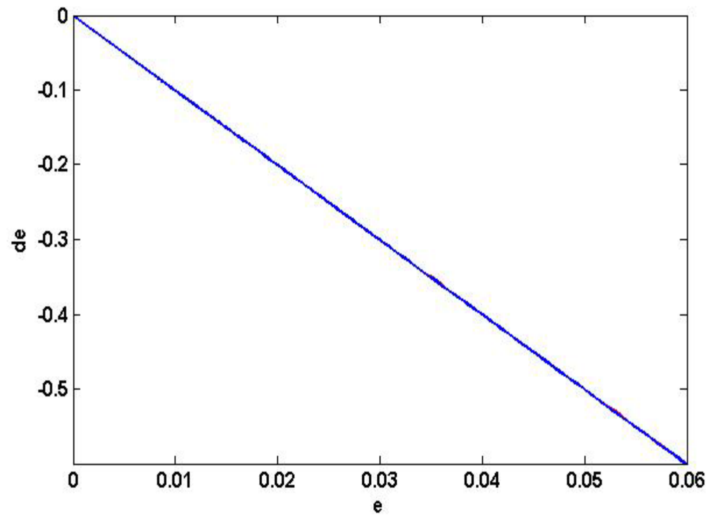

Fig. 5: Phase path of self-adaption sliding-mode control

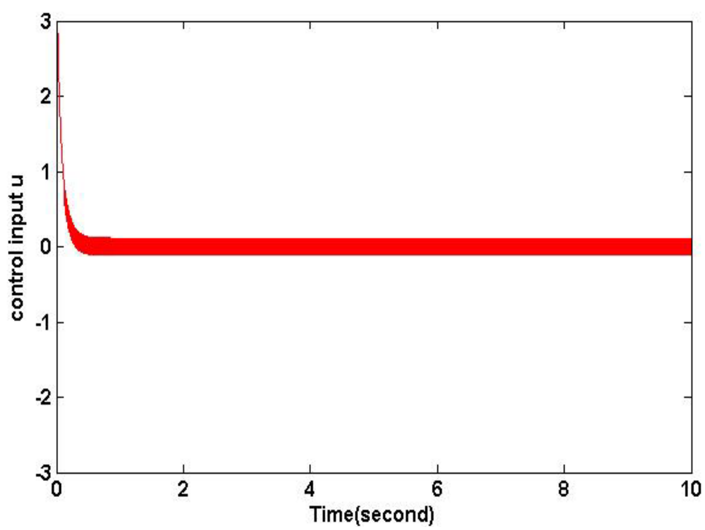

Fig. 6: Input of traditional sliding-mode control

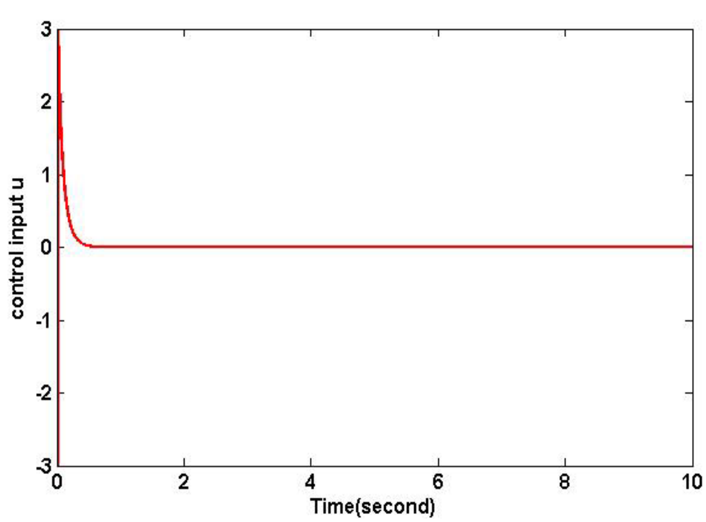

Fig. 7: Input of self-adaption sliding-mode

adaption sliding-mode control. The effect of these two control are accordance. Both of them have preferable tracking effect. Figure 4 and 5 represent the track status of traditional and self-adaption sliding-mode control respectively. The result indicates that traditional sliding-mode control is controlling, the track crosses back and forth in the sliding mode surface on both sides, shark exists. Figure 6 and 7 are the input signal of traditional and self-adaption sliding-mode control. Figure 6 indicates the input status of traditional sliding-mode control. From the figure, we can know that in this situation, the amplitude is bigger than the status in Fig. 7. In conclusion, the self-adaption sliding-mode control restrains the shark exist in traditional sliding-mode control efficiently.

CONCLUSION

- Sliding-mode control was used to controlling shunt-wound pick and place robot in this study. This study analyzed the reason of why shark exists when exponential reaching law was applied in discrete system, proposed a self-adaption reaching law sliding-mode control algorithm based on approaching coefficient ε adjust itself.
- The simulation result indicated that, the self-adaption sliding-mode control restrains the shark exist in traditional sliding-mode control efficiently.

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