Design of Uniform Speed Control System for the Inclined Multi-axis Linear Motion Unit

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Abstract

The paper studied a three-axis linear motion unit based on CAN bus and the uniform characteristic of speed was discussed. The multi-axis synchronization, speed precision and motion distance in the uniform speed motion sections should meet the requirements. The key points of the uniform control system included the acceleration method planning, motor control strategy and multi-axis control method based on the CAN bus. The implemented system showed that the precision of the uniform speed is 0.1% and the uniform distance is up to half of the whole motion distance.

Keywords: Multi-axis synchronization, Uniform control, Linear motion, Inclined surface

1. Introduction

The linear motor was adopted to implement the linear motion in the camera resolution detection system. Three linear motors were mounted on the flat surface, inclined surface of +40 degree and -40 degree, as seen in Figure 1. Linear motor has many advantages, such as simple structure, fast dynamic response, large speed and acceleration, high precision, small vibration and noise and so on (Cai, 2008, pp. 193-195). Currently, the linear motor combined with the closed-loop control system to implement the precision position servo control (Du, 2009, pp. 35-38). In the paper, the linear motors were used to provide uniform motion in the middle section. The control point of the motor is not the position servo, but the speed servo and which is different from the previous applications. According to the performance requirements of the camera resolution detection system, the speed range is from 50mm/s to 1500mm/s and the whole motion distance is 800mm. In the middle of the distance the speed is required to be uniform with precision of 0.1% and the uniform distance to be 400mm. In addition, the three linear motors should be start-up in the sequence. The multi-axis linear motion unit is employed to provide rapid start-up and smooth motion in the limited motion range. Therefore, the motion unit should be stable and firm to decrease the shaker during the motor's starting. The linear motion system adopted the linear motors of TBX2510 with peak thrust of 860N and maximum speed of 5200mm/s. The linear motor's transfer function is

$$G(s) = \frac{48.358}{0.001156s^2 + 1.45s + 34281.9}$$

2. Synchronism of the three linear motors based on the CAN bus

CAN (Controller Area Network) bus belongs to the field bus and it is a kind of serial communication network supporting distribution control. Its module construction only includes three layers: physics layer, data line layer and application layer. Now, it has widely applied in the industry field (Wang, 2010, pp. 158-160). CAN bus specified the data link and physical connection layers of a fast, reliable network based on the CAN application layer protocol (Copley, 2005, pp. 20-21 & Liu, 2010, pp. 75-77). It's a highly efficient synchronism control manner. The CAN control architecture was seen in Figure 2. The control loops are closed on the individual motor, not across the network. The master control section employs the network to transmit commands and receive the motors' position to coordinates the three motors. Every motor is a node of the network and its operation data are transmitted to the controller and then to CAN bus. The upper computer can exchange the data with the CAN bus to monitor the motors (Yi, 2010, pp. 78-80). In this part, the CAN nodes were adopted and the master control system programmed the motors' start-up sequence with their unique address. The CAN control system includes communication part, time sequence computation part and input-output part.

3. Acceleration method planning

It's very important to plan a reasonable acceleration method to obtain the uniform motion in the middle part. The force of the driving system has a direct bearing on the acceleration. The thrust force function of the motor (Zou, 2005, pp. 31) is

$$F_e = Mpv + Dv + w(t)$$

Where, F_e is the thrust force, M is the mass of the motor, p is the differential operator, v is the speed, $p\,v$ is the acceleration, D is the friction coefficient and $w(t)$ is the resisting force. The thrust force should change continuously to carry out the smooth control. Hence, the acceleration and speed should be changed continuously. The performance requirements for acceleration and deceleration control are continuous speed change, precision position without overshoot and rapid responds. In addition, the uniform motion range should be set clearly to synchronize the later control.

There were many speed curves used in the motion system. It was proved by the Matlab-software simulation that the S-shape accelerating/decelerating algorithm was the most suitable for linear motor motion control system because S-shape control can get rid of the smooth impulse with shorter acceleration time and less trace error (Hou, 2010, pp. 76-80). The system operation with S-shape acceleration strategy was smoother than that of the linear method and the longer the acceleration duration, the smoother the system status (Huang, 2005, pp. 55-59). However, the S-shape acceleration curve can not meet the middle uniform distance requirement when the speed was very high in the system.

Lots of experiments were conducted to determine the suitable acceleration strategy. The experiment results are seen in Figure 3, Figure 4 and Figure 5. The S-shape acceleration time in Figure 3 was longer than that of in Figure 4 and in Figure5 the linear acceleration was employed. The smooth control advantage was very obvious in the S-shape method. However, the uniform precision was nearly the same. There are two reasons. The one is that the load mass is very large, so the inertia is very large and the shake is very small. The other reason is the steady error of those acceleration methods in the type-II system is zero. The respond time for steady in the practical system is very short. In the uniform control system, the S-shape acceleration mode is employed when the uniform motion distance can meet the requirements and linear acceleration mode was employed when the acceleration was very large.

4. Compensation control for the special motion sections

The speed range of the linear motion unit is very wide from 50mm/s to 1500mm/s. There are two special motion sections, which are low speed motion section (50mm/s-100mm/s) and high speed motion section (1000mm/s-1500mm/s). The friction influenced the uniform control greatly and the friction compensation control was employed in the low speed section. There is great perturbation torque when the motor is start-up in the high speed section and torque compensation was employed in the high speed section.

4.1 Friction compensation control

The friction compensation control subsystem includes friction model coefficient identification and feed forward part design.

4.1.1 The identification of the friction model coefficient

The friction model of Lugre is a dynamic model and in this model friction described as a function with arguments of the relative speed and displacement. The friction equation is (Zhai, 2005, pp. 31-32)

$$\begin{cases} F = \sigma_0 z + \sigma_1 \dfrac{dz}{dt} + Bv \\[2mm] \dfrac{dz}{dt} = v - \dfrac{|v|}{g(v)} \cdot z \\[2mm] g(v) = \dfrac{1}{\sigma_0}\left[F_c + (F_s - F_c)e^{-(v/v_s)^2} \right] \end{cases}$$

Where, v is the relative speed of the surfaces, F_c is the Coulomb friction force, F_s is the static friction force, v_s is the STRIBECK-speed, σ_0 is the rigid coefficient, σ_1 is the damping constant and B is the adhesive friction coefficient. The static friction equation can be obtained by the friction equation when $dz/dt=0$. Thus, the static equation is

$$F = \left[F_c + (F_s - F_c)e^{-(v/v_s)^2} \right] \cdot \operatorname{sgn}(v) + Bv$$

The parameters of F_c, F_s, v_s and B need to be identified. The values of F and v can be obtained by the constant-speed experiments. The parameter can be identified by the improved QPSO algorithm.

4.1.2 Improved GQPSO algorithm

The Gaussian quantum-behaved particle swarm optimizer (GQPSO) was an efficient algorithm to optimize the search progress. Particles' number is m and the searching space is D-dimension. The particles searching operation was performed as the following equations (Kang, 2007, pp. 40-42)

$$\begin{cases} mbest = \dfrac{1}{M} \cdot \sum_{i=1}^{M} P_i = \left(\dfrac{1}{M} \cdot \sum_{i=1}^{M} P_{i1}, \quad \dfrac{1}{M} \cdot \sum_{i=1}^{M} P_{i2}, \quad \cdots, \quad \dfrac{1}{M} \cdot \sum_{i=1}^{M} P_{iD} \right) \\[3mm] x_{id}(k+1) = p(k) \pm \alpha \cdot |mbest - x_{id}(k)| \cdot \ln\left(\dfrac{1}{u} \right) \\[3mm] p = \dfrac{r_1 p_{id} + r_2 p_{gd}}{r_1 + r_2} \end{cases}$$

Where, $mbest$ is the optimal position of the individual particle, k is the current iteration coefficient and α is the shrinkage-expansion coefficient. u, r_1 and r_2 are the random numbers with uniform distribution. In the improved GQPSO algorithm, the random numbers' probability is the absolute Gaussian distribution between 0 and 1 and their probability expression is

$$p = |N(0, \quad 1)|$$

The probability distribution is different from the references (L.S., 2007, pp. 290-294) and this method was called to be GQPSO-algorithm in the simulations. The simulation results for the GQPSO-algorithm and improved-GQPSO algorithm were shown in Table.1. The simulation results were the average values of maximum error, minimum error and the average error for 100 generations evolution and the simulation programs were conducted 100 times. From the simulation results, the error of the improved- GQPSO algorithm was less than that of the GQPSO-algorithm.

With the improved-GQPSO algorithm, the coefficients of the friction model were identified as

F_c=0.00780, F_s=0.3212, v_s=0.4025, B=0.1931.

The dynamic parameters of the friction model are showed as following with the same algorithm.

σ_0=1200.3$N \cdot m \cdot rad^{-1}$ and σ_1=4.02 $N \cdot m \cdot rad^{-1}$

4.1.3 Friction feed forward control design

The traditional friction compensation introduced the friction into the feedback loop, which brought the unsteady factors as well. The feed forward compensation cannot alter the steady of the system and the control precision can be improved (Hou, 2009, pp. 56-58). So the friction feed forward control was employed in the low speed control part.

4.2 Torque compensation control

In the high-speed motion section, the start-up torque is very large. So the acceleration feed forward coefficient

should increased to accelerate the compensation progress. However, the feed forward coefficient was different for the motor mounted on the inclined surface. Because of the same stress of the motor in the same direction, the difference was not very obvious. The coefficients were adjusted according to the real engineering.

5. Conclusion

The experiment results were shown in Figure 6, Figure 7 and Figure 8. The speed uniform characteristic was required in the forward motion, whose speed was greater than zero in the speed figures. The motor speed and position were measured real-time. Figure 6 was the speed curve for the motor mounted on the inclined surface of -40°and its ordered speed was 50mm/s. Figure 7 was the speed curve for the motor mounted on the flat surface with ordered speed of 500mm/s. Figure 8 was the speed curve for the motor mounted on the inclined surface of +40° with ordered speed of 1500mm/s. According to the computation results, the uniform speed error is 0.0998% and the uniform distance is 402mm, which meet the system requirements. Currently, the multi-axis linear motion unit has applied in the camera resolution detection system.

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Table 1. The simulation results of the GQPSO and improved GQPSO

Algorithm Type	Maximum of the error	Minimum of the error	Average of the error
GQPSO	0.0068	0.0000	0.0007
Improved GQPSO	0.0051	0.0000	0.0006

The simulation results for the error of the objective function showed that the error with the GQPSO algorithm was larger than that of the improved GQPSO algorithm.

Figure 1. The structure of the motor mounted on the inclined surface

The linear motion unit mounted on the inclined surface included linear motor, grating rule, load and other auxiliary devices.

Figure 2. The CAN control architecture

The CAN control system included monitor part, three process and communication parts.

Figure 3. The speed curve with the longer S-acceleration time

The speed was uniform and the system was stable when the motor stopped moving with the longer S-acceleration time in the S-shape acceleration mode.

Figure 4. The speed curve with the shorter S-acceleration time

The speed was uniform and the system was not as stable as that of in Figure 4 when the motor stopped moving with the shorter S-acceleration time in the S-shape acceleration mode.

Figure 5. The speed curve without the S-acceleration time

The speed was uniform, but the system was not stable when the motor stopped moving in the linear acceleration mode.

Figure 6. #1 motor's speed curve with ordered speed of 50mm/s

#1 motor's speed was ordered as 50mm/s and its error was less than 0.04mm/s in the middle motion section and the uniform distance was more than 450mm.

Figure 7. #2 motor's speed with ordered speed of 500mm/s

#2 motor's speed was ordered as 500mm/s and its error was less than 0.41mm/s in the middle motion section and the uniform distance was more than 450mm.

Figure 8. #3 motor's speed with ordered speed of 1500mm/s

#3 motor's speed was ordered as 1500mm/s and its error was less than 1.4mm/s in the middle motion section and the uniform distance was more than 402mm.