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Dual-motor synchronous control technology based on EtherCAT

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Abstract. In order to solve the problem of position synchronization of two-motor coordinated control, this paper proposed a dual-motor position synchronization control system based on the industrial Real-time Ethernet——EtherCAT Technology. In this paper, the overall design scheme was put forward, and the synchronization mechanisms and algorithms of DC (distributed clock) were mainly analyzed. Experiments were carried out on the double-drive box transfer mechanism of the experimental platform, and the experimental results showed that the positions of the two motors was well synchronized, meeting the design requirements.

1. Introduction

With the continuous improvement of the industrial automation, the dual-motor or multi-motor co-driven scheme has been widely used in various fields [1-3]. Compared with the traditional mechanical synchronization method, the multi-axis motion control system with simple structure and good flexibility has received more and more attention and application. Therefore, studies on the synchronous drive of motors are of great significance for the development of multi-axis motion control systems.

EtherCAT is an industrial real-time Ethernet technology provided by Beckhoff, Germany, with a bus utilization of 97% and a highly accurate distributed clock, of which each node can achieve a synchronization accuracy of less than 1 microsecond. With EtherCAT's advantages of high speed and high precision, the application of EtherCAT to the synchronous control of motors can greatly improve the synchronous performance of the motors.

This paper proposed a dual-motor synchronous control scheme based on EtherCAT, realized the position synchronization control of two motors and carried out the synchronous motion control experiment.

2. EtherCAT operation mechanism analysis

EtherCAT takes full advantages of Ethernet full-duplex features, using media access control (MAC) of master-slave mode to realize the data exchange between the master and slave stations via dual-port RAM. The transmission of EtherCAT data frame utilizes the technology of "processing on the fly" to realize the insertion or extraction of process data during the transmission of data frames [4]. Because information processing is completely performed in hardware, the total delay introduced can be less than 100 ns, and the communication principle is as shown in figure 1.

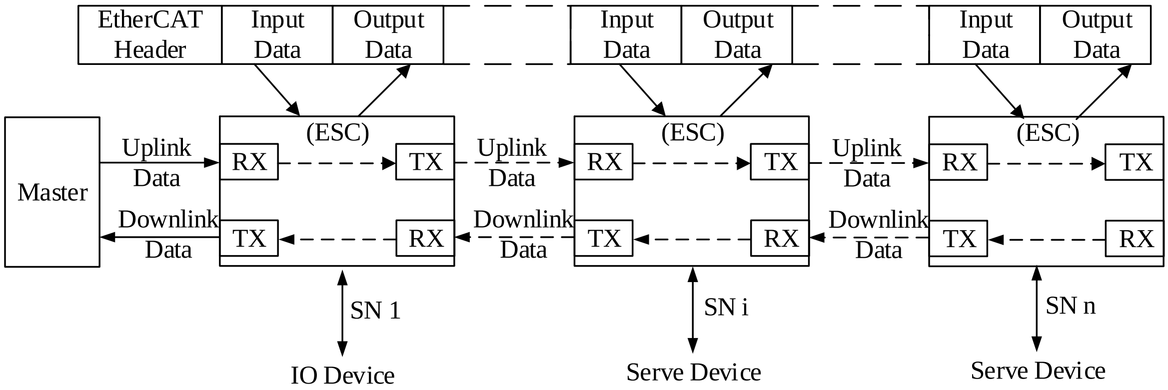


Figure 1. Operation mechanism of EtherCAT

Since both the master station and the slave station have independent and autonomous clock sources [5], in order to achieve accurate synchronization control of clock, it is necessary to measure and calculate the data transmission delay of the system and the initial offset of the local clock, and to constantly dynamically compensate for drift of the local clock [6]. Let t_{sys_ref} be the time T_1 when the data frames sent by the master station arrive at the slave station of the reference clock, and let the time t_{local}(n) of local clock of the salve station be T_2(n) when the data frames arrive at the slave station; When the data frames return, the time of the local clock t_{local} (n) when the data frames arrive at the slave station n is T_3(n) and the time when the data frames arrive at the slave station of the reference clock is T_4. The transmission delay T_{delay}(n) between each slave station and the slave station of the reference clock can be calculated by the following formula:

$$T_{delay}(n) = [(T_4 - T_1) - (T_3(n) - T_2(n))]/2 \tag{1}$$

The initial offset T_{offset}(n) between the local clock of each slave station and the reference clock can be calculated by the following formula:

$$T_{offset}(n) = T_2(n) - T_1 - T_{delay}(n) \tag{2}$$

According to T_{delay} and T_{offset}, the drift of the local clock can be calculated by:

$$\Delta t = t_{local}(n) - T_{offset}(n) - T_{delay}(n) - t_{sys\_ref} \tag{3}$$

The time control loop adjusts the running speed of the local clock based on Δt, to realize the drift compensation of the clock. Under normal circumstances, local time increases by 10 units every 10 ns, but 9 units every 10 ns when $\Delta t > 0$, and 11 units every 10 ns when $\Delta t < 0$ [7], as shown in figure2.

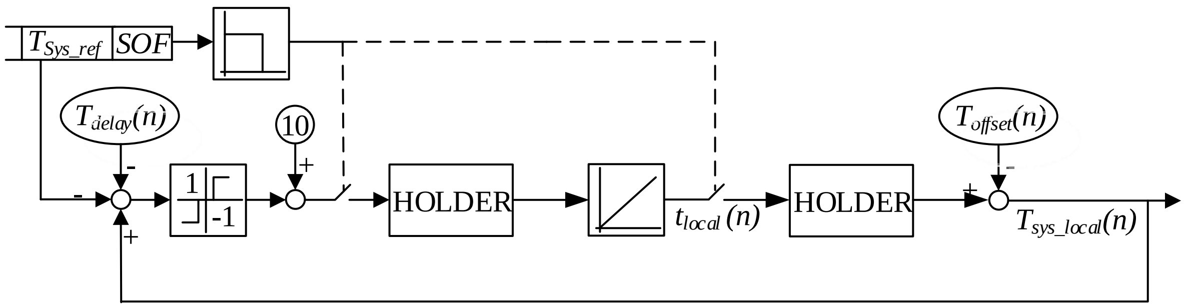


Figure 2. Principle of clock compensation

After the initialization of the distributed clock is completed, the master station periodically sends a command to read the system time of the reference clock, and writes it to other slave stations, thereby compensating for dynamic clock drift and realizing clock synchronization control.

3. Dual-motor synchronous control system

The diagram of a type of double-drive box transfer mechanism is shown in figure 3. When the box is transported, the two motors simultaneously drive the box to move. Since there is no mechanical coupling to achieve coordinated synchronization of the bearing axle, in order to avoid the jam caused by the displacement difference of the box, it must be ensured that the displacement of the motor-driven chain is synchronized.

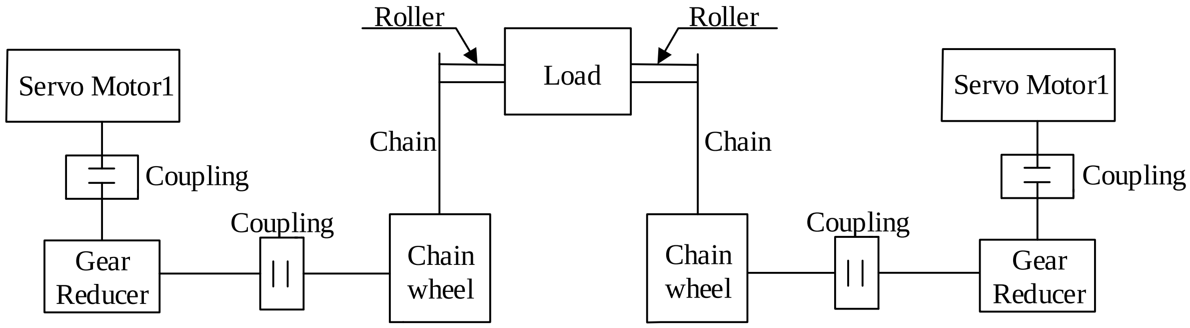


Figure 3. Diagram of mechanical drive

In order to realize the synchronous control of the motor, the motor synchronous control strategy adopts the cross-coupling control method [8]. The system is mainly composed of Protocol Conversion Module (PCM), control machines, servo drives, permanent magnet motors and position test devices. The protocol conversion module serves as the EtherCAT master station, while the motion control module serves as the slave station. The master and slave stations communicate via the EtherCAT bus, and the motion control module exchanges data with the position test device via the CAN bus and the driver. The control architecture is shown in figure 4.

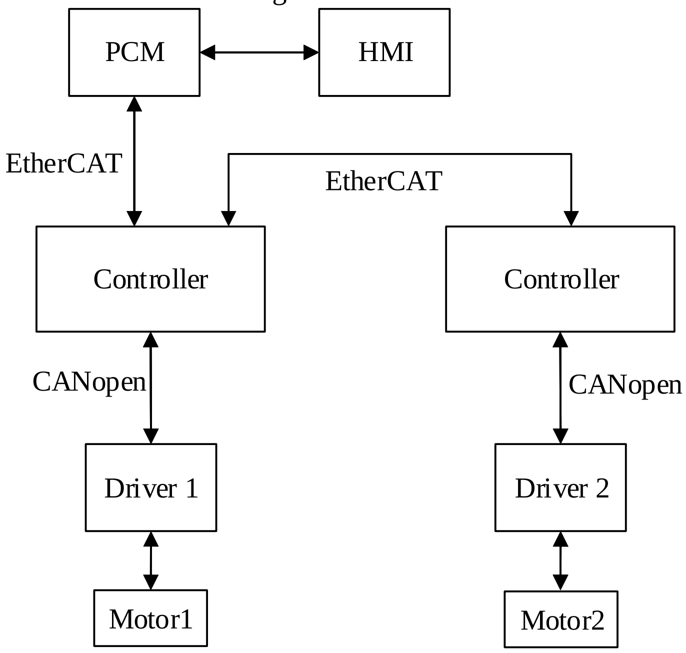


Figure 4. Control archite of the dual-motor synchronous control system

A synchronization signal is generated according to the synchronized system time, used for interrupt control and triggering digital input and output. The communication time sequence is shown as figure 5. The motion control module (slave station) completes the copying of the data and calculates the output data before the Sync0 event, waiting for the start of Sync0. After the Sync0 signal occurs, after a short hardware delay, the application layer of the slave station completes the data processing and calculation in the interrupt service program, and acquires the expected speed of the motor, updates the servo driver data, and realizes the synchronous control of the motor.

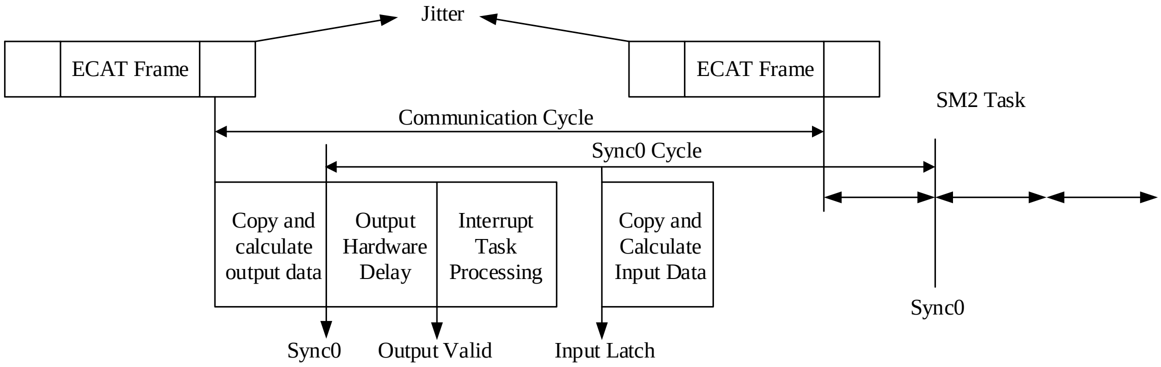


Figure 5. Communication time sequence

4. Test and verification

In order to verify the validity and feasibility of the scheme, experiments on a dual-motor speed linkage and dual-motor position synchronization control strategy were carried out on a type of double-drive box transfer mechanism. In the dual-motor speed linkage experiment, the given motor running speed was 1200r/min, and synchronously operated for 2s. The given speed curve is shown in Figure6(a), while the actual running speed curves of motor 1 and motor 2 feedback by the driver are shown in Figure6 (b). From the results, the highest instantaneous speed of motor 1 was 1203r/min, and the lowest instantaneous speed was 1195 r/min. The highest instantaneous speed of motor 2 was 1205r/min, and the lowest instantaneous speed was 1193 r/min. The two motors had small fluctuations in speed and could be operated and stopped at the same time, indicating the good speed synchronism of the two motors.

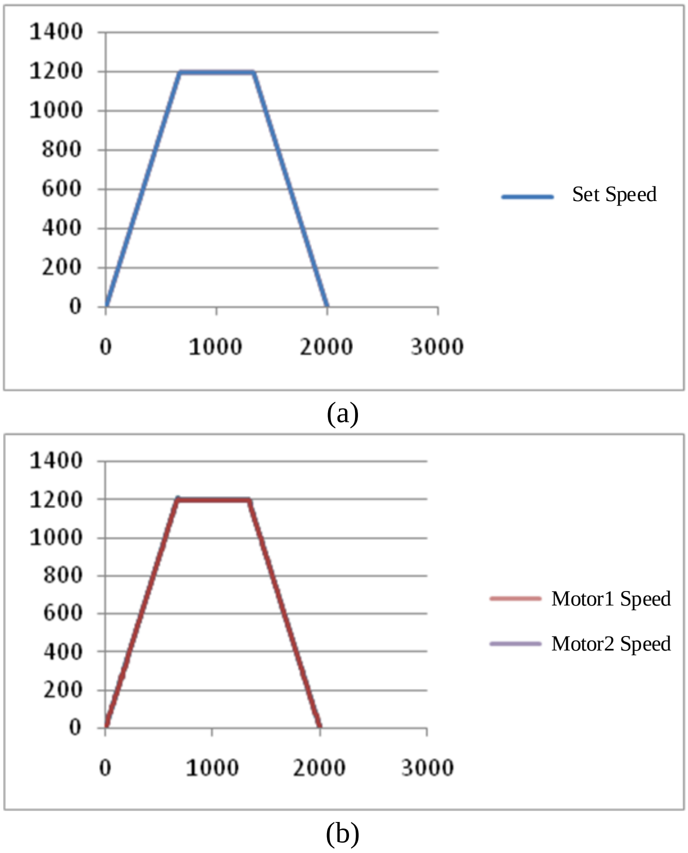
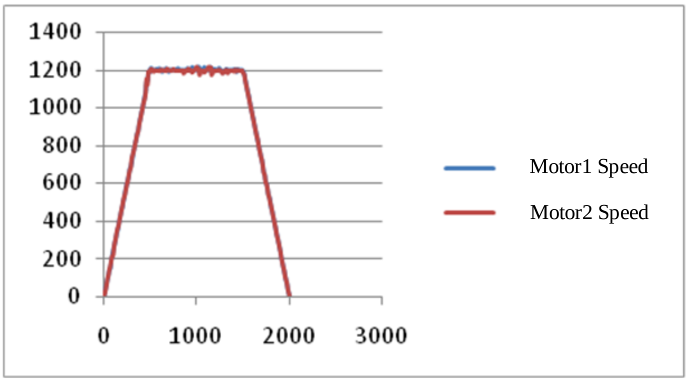
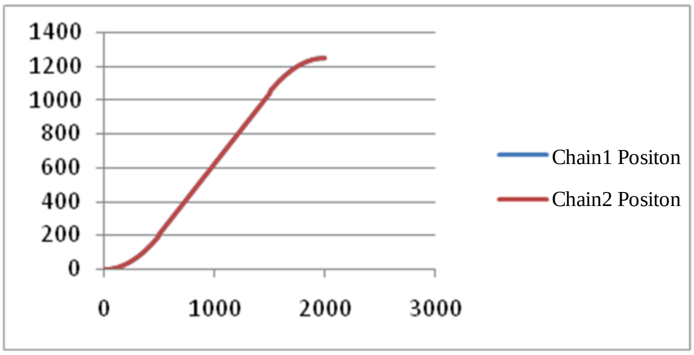


Figure 6.Speed curve waveform. (a)Set Speed. (b) feedback speed of motor

In the dual-motor position synchronous control experiment, the given running speed the motors was stable of 1200r/min, and the double-drive box has an expected displacement of 1.25m.The actual rotation speeds of the motor 1 and the motor 2 fed back by the driver are shown in Figure7 (a), and the chain displacement curves feedback by the position test device as shown in Figure7 (b). It can be seen from the results that the motor 1 and the motor 2 could almost reach the given speed of 1200r/min at the same time, run synchronously for 1 s at 1200 r/min and then stop after slow deceleration. The maximum instantaneous speed of motor 1 was 1210/min, while the minimum instantaneous speed was 1190r/min; The maximum instantaneous speed of motor 2 was 1209r/min, while the minimum instantaneous speed was 1185r/min; The maximum displacement error of two chains was 0.1mm, and the two chains could reach the given position almost simultaneously, indicating the good synchronous control performance of the two motors.



(a)



(b)

Figure 7.Speed and position curve. (a)motor feedback Speed. (b) position of chain

5. Conclusions

In this paper, the communication mechanism of EtherCAT and the synchronization control mechanism of distributed clock were analyzed, and a dual-motor synchronous control system based on EtherCAT was built. In order to test the validity and feasibility of the scheme, experiments on a dual-motor speed linkage and dual-motor position synchronization control strategy were carried out on a type of double-drive box transfer mechanism. The experimental results showed that the designed dual-motor synchronous control system had a good performance in synchronous output and an accuracy of position synchronization control, which can be applied in the occasions where the requirement of position synchronization accuracy is relatively high.

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