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Motion Control System using SERCOS over EtherCAT

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Abstract

SERCOS interface (SErial Real time COmmunication Specification) is known as a universal 'motion control' interface, while EtherCAT (Ethernet for Control and Automation Technology) is a high-speed, real-time, topology-flexible industrial ethernet for data communication in process automation and factory automation control system. In order to implement the SERCOS interface on the EtherCAT network, a SERCOS over EtherCAT (SoE) model is used in this paper. By introducing statemachine mapping and data mapping method, the SERCOS statemachine, service channel, IDNs and all kinds of telegram can be supported by EtherCAT. Simultaneously, EtherCAT is accessible to the servo profiles and drive parameters defined by SERCOS. The SoE model ensures the transmission of real-time motion control data in a maximum speed. For illustration, a high speed multi-axis SoE motion control system is developped which operates the highly synchronized movement with multi-servo drivers. The system which combines SERCOS interface with the advantages of Ethernet structure shows the outstanding real-time behavior. This paper provides a kind of brand-new control plan for the numerical control equipment and industrial robots.

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Keywords: EtherCAT; SERCOS; SoE; Motion Conrol System

1. Introduction

Industrial ethernet fieldbus, the computer network technology used in the industrial automation field, palys an important role in the development of current industrial control fieldbus technology[1]. A number of techniques are used to adapt ethernet for the needs of industrial automation, such as real time behavior and rich bandwidth. EtherCAT is an outstanding new one in many kinds of industrial ethernet fieldbus solution. SERCOS is recognized as a real-time communication interface particularly for motion control applications[2]. The SERCOS association in Germany consists of many famous manufacturers such as SIEMENS, BOSCH, AMK and etc., and it has set up a standard between CNC unit and digital servo devices to ensure good interchangeability.

2. EtherCAT network

EtherCAT, originally developed in year 2003, has become an IEC (International Electro technical Commission) 61158-12 (type12) international standard since 2007. Because of its higher performance, more flexible topology and lower costs than other ethernet fieldbus technology, EtherCAT has been developing rapidly in factory automation and process automation. The system structure diagram is shown in figure 1. EtherCAT protocol applies a master-slave mode, in which the master device uses standerd 100BASE-TX ethernet adapter and the ESC (EtherCAT Slave Controler) uses an ASIC or a FPGA with EtherCAT IP (intellectual property) core to post and receive the EtherCAT frames[1]. In the beginning of the working cycle the EtherCAT master device posts an EtherCAT frame. When the frame reachs an ESC, the corresponding moudle of which analyses the address and location on the frame, decides

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which parts of the frame are the useful sections and then reads or writes data on this appointment section. When the read-write operation has been accomplished, the Working Counter (WKC) at the end of the frame is added by one, i.e. the data on the frame has been processed[3]. The ESC read-write process takes 10 nanosecend, thus it will cause a 10 nanosecend delay for the EtherCAT system. As figure shows, when the frame was processed by the last ESC, it was send back to the master. After the master device receives the returned frame and processes its data contained, one working cycle is accomplished.

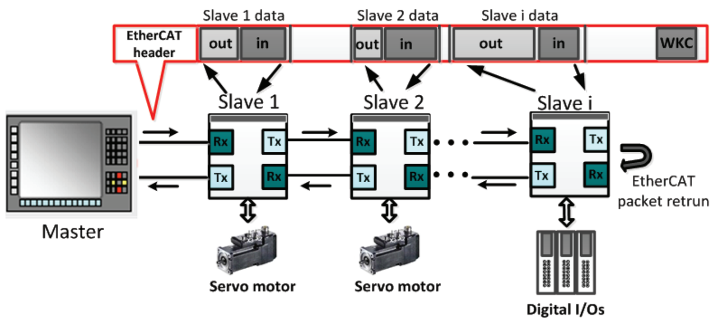

Figure. 1. EtherCAT System structure diagram in line topology

EtherCAT supports almost all kinds of topology structure, such as ring, line, star and tree. The transmission speed of EtherCAT is fixed to 100 Mbit/s with full duplex communication. The EtherCAT network is able to connect maximally 65535 devices via switch and media converter. The EtherCAT system can update 1000 I/Os in just 30 microseconds or exchange 1486 byte contents in 300 microsecond[3]. With this remarkable performance, the EtherCAT distribute servo controller can even be used as current loop or torque loop controler.

EtherCAT uses standard the IEEE 802.3 ethernet frame with a reserved type 0x88A4, which includes 2 byte header and 44-1498 byte data section. The data section is one or several EtherCAT datagrams, each datagram is corresponding to the independent operation to an ESC or its memory district. Besides, EtherCAT master is able to transmit EtherCAT frames which are packed into the UDP /IP packet using port 0x88A4. Those two kinds of frame structure are shown in figure 2.

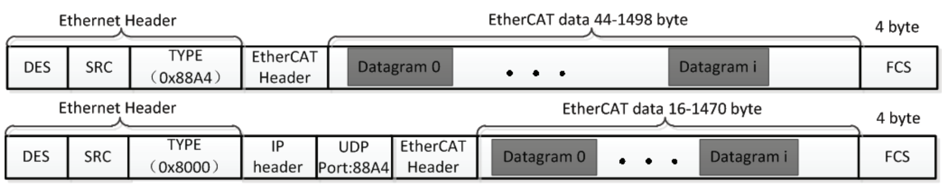

Figure. 2. (top) EtherCAT Standard Frames according to IEEE 802.3; (bottom) EtherCAT Frames using UDP/IP packet

3. SERCOS interface

The SERCOS interface which has become IEC 61491 international standard since 1995 is a specialized serial real-time communication protocol between industrial machinery equipment and digital servo device. It provides a comprehensive and rigorous definition of the physical layer, data link layer, data exchange structure and content. It gives a lot of servo profiles, data structures and processes commands to operate related machines and equipment. The SERCOS interface applies the ring topology structure a, one control unit can carry one or more SERCOS control rings and controls 254 servo devices at most. The control units, servo units and PLCs are connected by the bilateral optical fiber (in and out) in series to realize bilateral data communication. SERCOS transmission speed is from 2 Mbit/s to 16Mbit/s.

As SERCOS protocol defines, it specifies a collection of messages called “telegram” which traverse the ring in a fully deterministic manner. These telegrams exchange information between the controller unit and the slaves. There are 3 types of telegram: MST (Master Synchronous Telegram), MDT (Master Data Telegram) and AT (Amplifier Telegram). The SERCOS system takes five communication steps from CP0 to CP4 to reach a steady control state. CP0~CP3 is the interface initialization phase and CP4 is the normal synchronous control operation phase (a CP4 working cycle has been shown in figure 3). At the start of CP4, the control unit posts a telegram called the MST which ensures all drivers to receive message in full coordination, then each driver posts an AT which provides the slave’s information to the control unit such as position feedback. At the end, the control unit posts a Master Data Telegram (MDT) which contains all the control information to the drivers such as position command and torque command.

The SERCOS supports two types of data transmission, cyclic and non-cyclic. Cyclic data is the critical real-time synchronized data sent between the controller unit and the slaves (drives, I/O modules). In every SERCOS cycle, the controller unit sends and receives fixed-length messages to the drives and I/O modules. These messages contain the motion control command signal and the feedback response for each drive or the digital I/O commands and responses for each I/O module. The cyclic data is guaranteed to reach each drive and I/O module and return to the controller unit at a fixed time interval.

Non-cyclic data is the noncritical asynchronous data. The cyclic fixed-length messages have space (called the Service Channel) reserved for non-cyclic data. In each cycle, the Master may transmit two bytes of non-cyclic data through a Service Channel to each Slave. Note that it may require several SERCOS cycles for the Master to complete the transmission of the non-cyclic data to the Slaves. Typically, transmitting non-cyclic data is much slower than cyclic data.

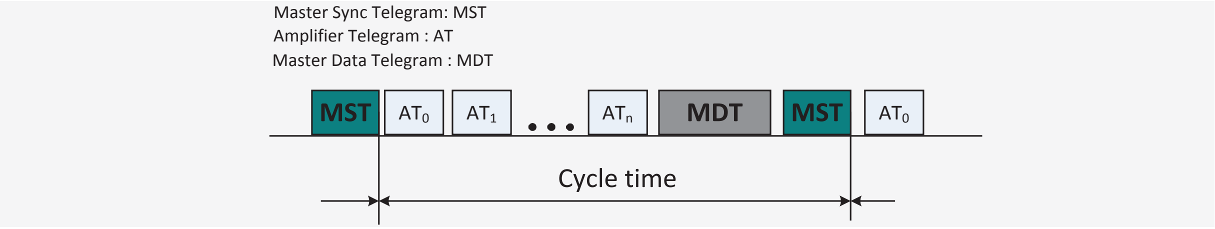

Figure.3. SERCOS working cycle in normal operation phase

4. Implementation of SERCOS on etherCAT

The SoE model will integrate drives based on SERCOS technologies in an EtherCAT environment. It includes the IEC 61491 state machine (Communication phases), synchronization, process data communication and the access via Service Channel to the unique identification number (IDN) and each IDN is in correspondence with a data block which possesses all the useful information of IDN. The elements in IDNs are data state, attribute, name, unit, min, max and value.

4.1. Statemachine mapping

According to the analysis, EtherCAT has a more flexible topology stuctrue than SERCOS, furthermore, its transmission speed is faster than SERCOS by two orders of magnitude. Additionally, the EtherCAT has a technique called distributed clock to enable the ESC to be synchronized with a deviation of significantly less than one microsecond. In order to obtain a high transmission speed, flexible topology, less synchronization jitter industrial ethernet fieldbus for motion control field, the SERCOS protocol is implemented on the EtherCAT network.

The state of the ESC is controlled via the EtherCAT State Machine (ESM). Depending upon the state, different functions are accessible or executable in the EtherCAT slave. Specific commands must be sent by the EtherCAT master to the device in each state. There are four states in ESM: Init, Pre-Operational, Safe-Operational and Opertional.

In order to make SERCOS and EtherCAT compatible, The SERCOS comunication phases are accommodated to the EtherCAT state machine (as figure 4 shows): phases 0 and 1 are covered by the Init state of the ESM. Phase 2 corresponds to the Pre-Operational state and allows access to the SERCOS IDNs via the EtherCAT mailbox which is a mechanism which implements a handshake mechanism for data exchange in a non-cyclic way. Phase 3 corresponds to Safe-Operational state, the cyclic data is transmitted and the driver has time for synchronization. The EtherCAT Safe-Operational state defines that the ESC has to transmit valid inputs and to ignore the outputs from the master which must be guaranteed by the ESC. In Operational state corresponding to phase 4 all inputs and outputs are valid[4].

It is worth to mention that EtherCAT allows a fallback from Operational to Safe-Operational or Pre-Operational and from Safe-Operational to Pre-Operational. Although there is no similar SERCOS fallback between phase 3, phase 4 and phase 5, a SoE slave should supports the fallback too. If not, the slave shall be in an error state.

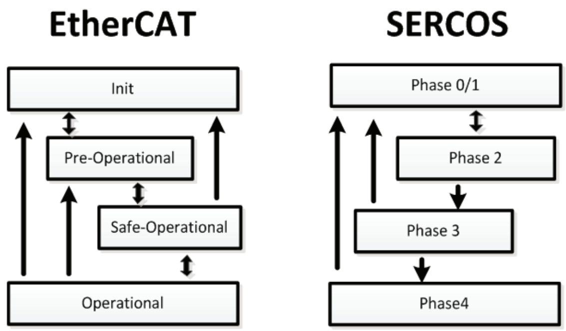

Figure.4. ESM and SERCOS statemachine

4.2. Data mapping

After the accommodation of EtherCAT states and SERCOS phases, on one hand SERCOS transfers non-cyclic data in the EtherCAT Pre-Operational, Safe-Operational and Operational state, the other hand SERCOS transfers cyclic data in the Operational state.SoE cycles are built using telegrams, which in turn contain data records for all of the Slave drives. Cyclic data is transferred in the cyclic data part of the data records. Non-cyclic data is transferred in the Service Channel of data records.

The IDNs are packed into the mailbox to send parameters and process command to the ESCs. In the EtherCAT frame, a four byte header following the mailbox header defines the operation mode and the data direction and which kinds of element are transmitted, additionally the multiple elements transmition of one IDN is possible. For cyclic data, The AT and MDT telegram are packed into the datagram of EtherCAT frame. EtherCAT frame is generated by the EtherCAT master in a precise synchronous cycle, thus the telegram exchange is in a good real time environment. One EtherCAT frame is able to transmit more cyclic and non-cyclic datas than SERCOS, thus it can set up faster communication and control more slave devices than SERCOS. Although the cyclic data and non-cyclic data transmition are independant, but they can be transmitted in the same frame as figure 5 shows. In this way SERCOS protocol has been implemented on the efficient industrial network EtherCAT.

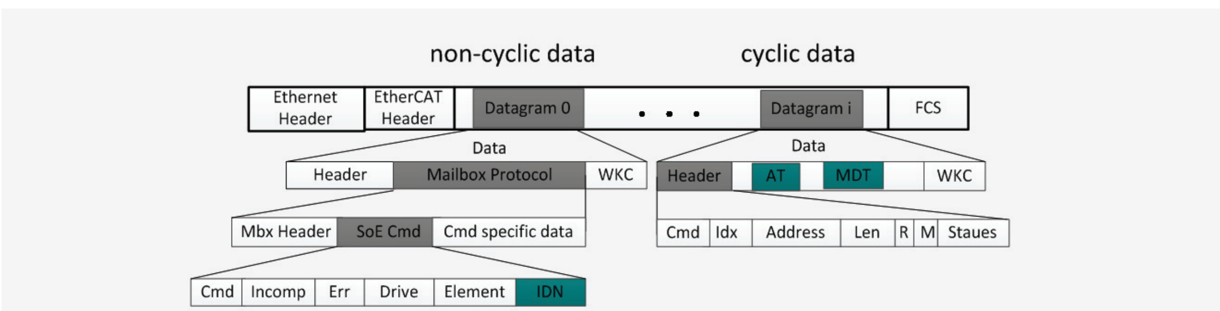

Figure. 5.SERCOS cyclic and non-cyclic data transmition in the EtherCAT frame

5. Multi-axis motion control system on twinCAT

According to the method above, a multi-axis motion control system is developed. The system includes one System Master (SM) and several Systerm Slave Units (SSU). A PC serves as the SM platform. An ESC and several suits of actuator which includes a NC-card, a HollySys driver and a servo motor serve as one SSU. A SSU can maximally install four suits of actuator. As the figure 6 (d) shows, in this experiment one SM and two SSUs was connetcted by 100BASE-TX twisted wire in a line topolgy structure.

The TwinCAT (The Windows Control and Automation Technology) from Bechhoff turns any compatible PC into the real-time controller with a soft PLC system, NC axis control, programming environment and operating station. The soft PLC system on TwinCAT programed in IEC 61131-3 ST (Structure Text) language is used as the EtherCAT master controler of the SM (figure 6 (c)), which is responsible for initializing the ESC, sending out position commond or speed commond in accordance with the synchronous period and conducting some non-cyclic operation. For the ESC, its task is to guarantee the normal communication with the SM, realize the SM's control intention and unpack the correct data from EtherCAT frames. The NC-card is a numerical controler, responsible for interpolation and giving the driving axis right pluse or analog singnal according to the data from the SM. The HollySys driver and the servo motor is used as a driving axis.

More SSUs can be added to the motion control system to form any kind of topolgy structure supported by EtherCAT, which almost has no effect on real-time and synchronization performance of the whole system. The system is working in a 4 millisecond synchronous period. Each axis can be operated under semi-closed loop position control or speed control strategy. Moreover, by writing IDN into the SSU, the SM is able to configure parameters, conduct diagnosis for each axis and operate each axis back to the original point.

6. Conclusion

In practice, the synchronous jitter of SM is less than 30 microseconds, and each axis is accurate in positioning, good in synchronization and smooth in rotation. Thus the SoE multi-axis motion control system has good real-time and accuracy perfermance. It is proved that the implementation of SERCOS on EtherCAT is successful and feasible. With the help of this multi-axis motion system, numerical control equipment and industrial robots in the field of factory automation and process automation can use SoE technology to improve its working performance.

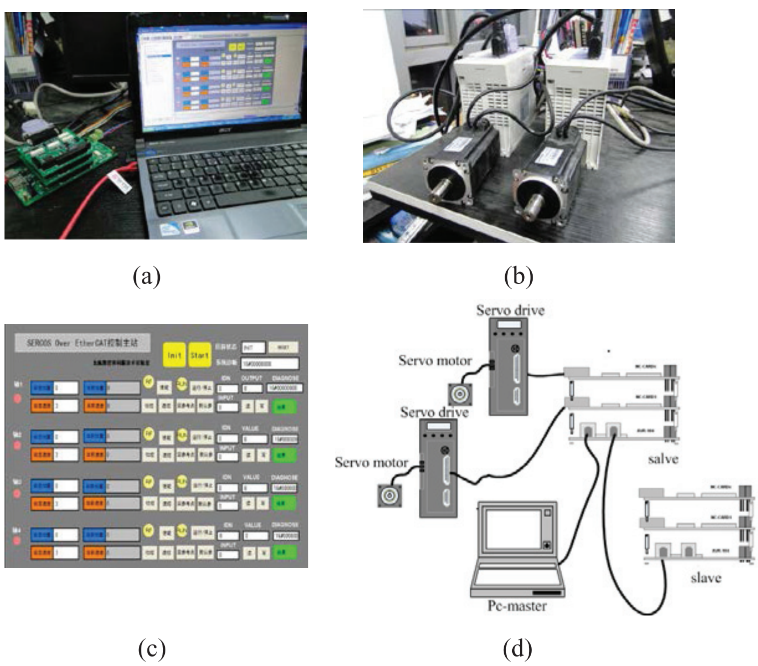

Figure .6. (a) System overview; (b) Driver and servo motor; (c) TwinCAT PLC control panel; (d) System diagram

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