A Research of Distributed Servo System Based on EtherCAT Bus
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Abstract: Aiming at the multi-motor collaborative servo control demand of electromechanical system, the distributed multi-motor servo control principles based on fieldbus are researched, adopting EtherCAT real-time Ethernet as the data communication fundamental network. Based on EtherCAT slave servo node of DSP, EtherCAT slave controller and embedded Master node, the multi-motor servo control system combined field and remote measurement, and control is built jointly. Aiming at the periodic and aperiodic control tasks in the system, the servo control and acquisition tasks are scheduled through real-time operating system in the embedded Master node to meet the real-time demand of the system. Meanwhile, in order to solve the synchronization problem between nodes of the distributed system, the timing unit is designed based on DC distribution clock and EtherCAT clock synchronization algorithm to realize slave synchronization function in network. The test result shows that, the distributed multi-motor servo control system is running stably and reliably with high timeliness, and the synchronization precision between nodes of the servo slave is less than 1 us, with high application value.

Introduction
In recent years, digital signal processing controller (DSC) and FPGA are combined with the servo motor control more and more closely to realize high performance of servo motor, and networked digital control has become one of the research hotspots in servo control field[1,2]. Currently, multi-motor servo control has been broadly used in various motor-driven automatic control systems during the production processes such as dosing, transmission, industrial robot etc. Coordinated control between multi-motor servos in the servo system may directly influence the production efficiency and product quality, thus how to manage efficiently, apply conveniently and control in real time are important problems to be solved in application field of multi-motor servo system. Therefore, the paper proposed a kind of design program for distributed multi-motor servo control system based on industrial real-time Ethernet EtherCAT bus, which designed a set of convenient and intelligent multi-motor servo control systems with simple structure, high timeliness and strong expandability [4-7].

EtherCAT bus is a kind of industrial real-time Ethernet proposed by Germany Beck of Company. It is based on standard Ethernet technology, with flexible network topology structure and simple system configuration, adopting full duplex communication mechanism, characterized in high speed and efficient data rate etc., and the valid data efficiency can be up to 90% above at most. The paper designed and realized the multi-motor servo control system based on EtherCAT, which can realize collaborative control for several kinds of motors such as permanent magnet synchronous motor, brushless DC motor, induction motor and stepping motor etc., and the network modular design may provide the system with extremely strong expandability [3, 4].

System Structure
The system is composed of two parts: field measurement and control network and remote network monitoring system. The field measurement and control network mainly realizes monitoring for operating status of each servo node in the operating site and real-time processing and data display for user requests by using EtherCAT bus.
The field node, including EtherCAT slave controller and servo motor, is the basic component of the system, and each control unit is corresponding to one controlled object—motor. The remote network monitoring system is based on matured Ethernet technology, which can realize remote monitoring function for several field measurement and control network systems.

The field measurement and control network of the system is a multi-motor servo control system based on EtherCAT bus, with the structure shown in figure 1. The system is composed of field upper computer, remote upper computer; EtherCAT embedded Master node, EtherCAT bus network, EtherCAT slave controller and field servo motor.

The field upper computer controller includes PC workstation and EtherCAT system management software. The system management software is operating on PC workstation, which is mainly used to test system configuration, so as to monitor the sampled data and waveform, realize fault diagnosis of testing system, and complete XML file input and output of system configuration.

EtherCAT embedded Master node is based on real-time operating system, which is used for system operating status and task scheduling and controlled through carrying out status computer, to complete initialization, task scheduling and related register operation of all the local slave devices.

EtherCAT network is the data carrier for realizing field servo node control, and the data transmission between the digital servo and control system is divided into periodic and aperiodic data. Periodic data includes the command and feedback information participating in control of real-time position, speed and torque etc. of the controller, and this kind of data requires higher transmission speed and frequency, with high timeliness requirements; aperiodic data includes the information such as controller parameter setting, function setting, diagnosis function, servo status, field temperature and humidity and alarm etc., and the timeliness required by such data is relatively weak.

EtherCAT slave control unit includes EtherCAT slave controller and servo motor, which realizes data communication with EtherCAT bus through ESC (EtherCAT Slave Controller) on one aspect, and completes high performance control of servo motor on the other aspect.

**System Operating Principles**

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The system adopts bus master and slave operating mode in structure, branch structure is allowed to be used in any position within the EtherCAT network section in EtherCAT slave data frame processing mechanism, which can guarantee not to damage the logical loop of the system.

EtherCAT bus can form various topology structures in branch structure, such as star-shape, tree form, daisy chain, and linear structure, which can also realize combination structure of various topology logics, so as to make the system be more flexible and convenient in actual laying.

Several EtherCAT slave controllers can be distributed and installed in the required position of industrial site, with corresponding functional modules selected for different servo motors for measurement and control. Modulated box structure is adopted for each slave controller, which also include several types of data acquisition modules, to complete acquisition and record tasks of asynchronous bus signal such as analog parameter, digital signal, CAN bus, RS485 and RS422 etc.

System initialization and control is launched by the Master node, with downstream message sent by the Master node, and the maximum valid data length of the message is 1.498 bytes. Data frame is distributed in all the slave devices. The slave device will analyze the message addressed to the slave module when the data frame passing, and read and write the message data in the appointed location according to the command in the message head, and the slave hardware will add 1 for the message working counter (WKC) to indicate that the data is processed. The process is realized by the processing chip ET1100 of EtherCAT protocol, with processing delay of about 10 ns. After the data frame arrives at the last slave module of the system logical position, the slave module will return the processed data frame to the Master node as upstream message. Upon receipt the returned message, the Master node will process the message and data until the communication process of the message is finished. The communication principles of the system are as shown in figure 2 [4].

During system operation, the configuration host will perform fast programming and configuration for the whole system according to the demands of control task, compile the XML configuration file according to the definition rules, and transmit the configuration file to the embedded Master node controller through the gigabit Ethernet configuration interface.

Upon receipt the system configuration file, the embedded Master node controller will resolve the configuration file, call the corresponding program according to the configuration contents, to perform configuration to the system, initialize the embedded Master node controller and each slave controller, and dispatch data transmission stream and servo control tasks of the whole system.

Upon receipt the initialization command of the Master node, each slave controller will initialize the operating mode of each slave, and realize data acquisition and servo motor control according to the requirements of the control command.
Hardware Design

Embedded Master Node

The embedded Master node can realize the functions such as unified programming, time synchronization of each slave controller, synchronous acquisition control, acquisition data receiving, data packing, network output and high speed data saving etc. of acquisition module of each slave.

The hardware platform of embedded Master node controller is realized through the method of FPGA+CPU. The hardware platform functions are designed as showed in figure 3.

CPU unit mainly provides necessary support for operation of the operating system, loading of TCP/IP protocol, debugging and operation of application.

FPGA hardware logical part provides the grouped exchange function and grouped data hardware collaborative processing function, which mainly provide support for exchange function of the communication interface, and perform collaborative processing for the data and perform hardware collaborative processing for the related communication protocol and data saving format.

![Figure 3. Design Block Diagram of Embedded Bus Controller Hardware.](image)

EtherCAT Slave Servo Node

EtherCAT slave servo node is formed with DSP processor TMS320F28335 as core. The processor is the special DSP chip developed aiming at the motor control field, which integrated high-speed core and rich motor control peripheral circuit inside, with high calculation speed, which is very suitable for driving each type of motors. The field servo control node is designed with the chip, and most of the motor debugging and control tasks can be realized with fewer peripheral element. Field servo node is designed as shown in figure 4.

EtherCAT slave in the paper is based on the ESC protocol processor of BECKHOFF Company, with slave functional modules with different functions designed according to the actual demands of the testing system [2, 7, 11].

Synchronous sampling is the key technology for distributed multi-motor servo control system. The synchronization precision of the system may directly determine the control performance and application scope of the multi-motor servo system. The system performs synchronization with GPS master clock at the frequency of 1Hz based on the slave controller and DP83640, to achieve...
microsecond level synchronization precision. Based on this synchronization method, the system slave will perform clock synchronization for each slave unit within the network section by using ESC distributed clock, so as to realize clock synchronization function between systems based on the EtherCAT bus.

![Figure 4. Field Servo Node.](image)

**System Software Design**

System software design is divided into EtherCAT Master node software design, servo node software design and system configuration management software design.

**EtherCAT Master Node Software**

The embedded Master node shall pass the following processes from electrifying to stable operation of the system: hardware network sheet file loading, operating system loading, slave initialization, system synchronization and cycle tasks etc.

Meanwhile, in order to meet the actual demands, the initialization of embedded Master node is divided into two modes: the first one is configuration mode, when the system is booted for the first time or requires modifying the configuration information in follow-up booting, PC machine will send XML configuration information to the embedded Master node through gigabit network port, so as to set the operation mode of the Master node to configuration mode. In configuration mode, the Master node shall complete some necessary configuration and write the configuration information of the slave to EEPROM of each slave; the second one is operating mode, and the system is in operating mode in default. In operation mode, each slave will save the configuration information in EEPROM through loading to perform initialization automatically.

**Servo Node Software**

The servo node transmits and receives data through EtherCAT bus, meanwhile, transmits remote commands and parameter actions according to the industrial personal computer, to complete control tasks for the motor. Servo node software includes: initialization module, motor control module, status monitoring module and data communication module. Where, modulated sequence structure commonly used in engineering is adopted in motor control module, with disconnection control mode adopted in Hall signal acquisition and parameter adjustment. In the paper, the common PID parameter regulating method is selected as the control mode for the motor.
Design of System Configuration Management Software

The system forms hardware foundation with IPC and NIC network card, and the configuration management software shall complete the functions such as initialization, topology structure identification, function parameter setting, and data display and saving etc. according to the actual measurement and control demands.

Data transmission and XML file interaction are realized between EtherCAT system management software and embedded Master node through sending the EtherCAT protocol frame supporting UDP. As the PC computer operating EtherCAT system management software is connected with the embedded Master node directly through Ethernet, the embedded Master node is addressed through the method of sequential addressing to realize communication with the embedded Master node (the addressing address is 0). Upon receipt the data and command sent by the EtherCAT system management software through Ethernet, the embedded Master node will resolve the data and command according to the protocol, and require performing initialization and configuration for the slave within the system according to the corresponding commands.

![Figure 5. User Interface of EtherCAT System Management Software.](image)

The main interface of EtherCAT system management software is as shown in figure 5, the contents of which include: waveform display and record unit, EtherCAT debugging assistant unit, status display unit etc., and the functions such as system topological identification and parameter setting etc. are realized through the operating menu on the main interface [9-12].

Result of System Test

The working condition of the system is described with node 6 in field 1 as an example. After checked node 6, input initial PID parameter and preset speed, and then click OK to transmit the setting parameters to the target node through EtherCAT bus, meanwhile, the program backend sends EtherCAT command frame to notify the target node to upload the related data, at this time, the upper industrial personal computer will complete display of the related receiving data as shown in figure 13-b. In the test, the controlled object of node 6 is a brushless DC motor with parameter of 270V and...
1kW. The control parameters of multi-motor are adjusted aiming at the above debugging result and speed curve to reach the best operating status. During multi-motor servo measurement and control of different fields, the whole multi-motor servo system is operating stably, without data conflict.

Meanwhile, two data acquisition systems are formed, with GPS time granting used between systems, two 14 bit data acquisition slaves are configured for each system configuration, the length of the data line between the slaves is 75 m, which perform acquisition of sinusoidal signal with the same sampling rate of 2 MHz and the same sampling starting time, operate the Master node program, to acquire the acquisition data from the two slaves, and draw the sinusoidal waveform acquired by the two slaves on a uniform time axis as shown in figure 8, and evaluate the synchronous sampling precision of the EtherCAT system through the phase deviation (caused by deviation of starting time of sampling) and partial waveform deviation (caused by sampling interval shaking). A and b in figure 6 are the acquisition data of the two slaves, and c is the difference between the data acquired in the same time of the two slaves.

There are 736,830 sampling points in the test, the minimum deviation of the data acquisition point in a and b is -0.002V, and the maximum deviation of that is 0.0027 V. Considering the sampling noise jamming, the system clock can reach the synchronization precision of up to 700 ns.

Conclusion
EtherCAT bus distributed multi-motor servo measurement and control network is of good timeliness and strong antijamming capacity, which takes full advantage of the field bus technology, to provide efficient and flexible measurement and control program for debugging of the control rate of motor driving system and multi-motor servo control. The system has rich interface, high synchronization precision, fast transmission rate and strong expandability, thus, it can meet the timeliness requirements in multi-motor servo control, meanwhile, the technology can be expanded to the collaborative servo control fields with high precision such as numerical control device and industrial robot etc.

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References
[8] System standard for the AGATE airplane avionics
