

## Large-scale Networked Multi-axis Control Solution using EtherCAT and Soft Logic

Zhiyuan Cheng<sup>\*1</sup>, Qing Ma<sup>2</sup>, Minqi Yan<sup>1</sup>, Yu Zhang<sup>1</sup>

<sup>1</sup>Xi'an institute of optics and precision mechanics of Chinese Academy of Sciences, Xi'an, 710119, China

<sup>2</sup>Xi'an University of Architecture and Technology, Xi'an, China

\*Corresponding author, e-mail: czy@opt.ac.cn

### Abstract

*Aiming at the deficiencies of the traditional multi-axis control solution such as complex networked structure, poor clustered-control feature and unsatisfactory engineering practicability, the paper firstly optimized the existing solution in networked fieldbus, controller model, engineering reliability and maintainability. Then it proposed a novel solution combined high speed real-time EtherCAT (Ethernet for control Automation Technology) fieldbus with soft logic controller. The new solution took advantage of extraordinary real-time performance of EtherCAT and made good use of powerful clustered-control architecture of soft logic controller. Thus the new solution is concise and effective to solve the Large-scale networked controlling problem of 1100 distributed motors. Compared with the traditional schemes, the engineering practice shows that the novel solution has the advantage of perfect real-time performance, powerful clustered-control capability, flexible and variable networked structure, excellent engineering practicability. The novel solution is worth using for reference in solve similar large-scale networked controlling problems.*

**Keywords:** large-scale distributed motors, EtherCAT, soft logic control, motion control

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### 1. Introduction

The distributed multi-axis motion control technology has been widely applied in various industrial fields, e.g, assembly lines, CNC machine tools, etc. With the widely application of the technology, it is becoming more and more critical. In recent years with the continuous expansion of industrial automation scale, the number of controlled motor is increasing more and more. At the same time, the accuracy and speed demand of system is also becoming higher and higher. So the traditional point-to-point motion control solution can hardly meet the new need [1-4].

Firstly, the traditional multi-axis control system is often composed of PLC (Programmable Logic Controller) or Industrial PC. And each PC or PLC exchanges information by a variety of fieldbus. These fieldbus include PROFINET, INTERBUS, PROFIBUS SERCOS, POWERLINK, and so on. However, the vast majority of above fieldbus cannot meet the accurate clock synchronization requirements for extraordinary high-speed motion control in which several axes carry out coordinated movements simultaneously [5].

Secondly, the unchangeable hardware architecture of PLC and PC hardly meet the need of flexible and variable large-scale distributed motor control systems. For example, once the number of controlled motor changes, the hardware and software of the whole system must be adjusted again, which is very inconvenient in engineering application. From the technical point of view, these traditional solutions inevitably have some defects: single interface, complex wiring, poor maintainability. They are only suitable for control of a few motors, not for large-scale networked control [6-7].

The aim of the paper is providing a control solution of large-scale networked distributed motors. In a specific project there are 1100 motors in total and each motor carries special optical device used to adjust optical path. We will centrally control 1100 stepper motors and separately accurate motion control of each motor. Unfortunately at present no solution perfectly meets the need of the project [8-10].

Aiming at the deficiencies of traditional schemes, the paper optimizes most of the existing solutions and proposes a novel solution which combines high-speed real-time EtherCAT fieldbus and software logic clustered-control technology. The extremely high speed of

the EtherCAT make real-time Ethernet possible, which could not be realized with traditional fieldbus.

## 2. Optimized Design of EtherCAT

Recently, with the standardization of the real-time Ethernet for industrial applications, Ethernet-based motion control systems are gaining increasing interest in networked control system. In the following, we will discuss the fieldbus architecture design of the novel solution.

### 2.1. Feature Analysis of Fieldbus

**Profibus:** As a low-cost communication fieldbus, PROFIBUS is widely applied in factory automation monitoring and control of the device layer. It's transmission speed can be selected in the range of 9.6k baud ~ 12M baud. Due to it's bus cycle costing about 10ms, which isn't qualified for the high-speed real-time motion control [11]. When it is used in large scale clustering motion-control system, it must connect external motor drives and wiring is complex and maintainability is poor.

**PROFINET:** PROFINET launched by the the PROFIBUS International Organization, is a new generation industrial Ethernet technology standard. PROFINET provides a complete network solution including real-time Ethernet motion control, distributed automation and so on. As a solution of Large-scale distributed control each SIMENS TCPU, networking by PROFINET fieldbus, at most control 32 motors which is unfavorable in large-scale networked control [12].

**EtherCAT:** EtherCAT is an genuine open real-time Ethernet in equipment layer, originally developed by Beckhoff Automation Ltd. EtherCAT sets a new standard for real-time performance and topology flexibility, at the same time, it also reduces the cost of fieldbus. EtherCAT is a genuine open real-time Ethernet in equipment layer. EtherCAT bus takes on strong real-time performance, simple wiring, compact structure. The EtherCAT fieldbus module can not only be easily replaced but also provides diagnosis function, improving the maintainability of the system.

In summary, EtherCAT is optimum in large-scale networked control. Thus the new solution adopts optimized EtherCAT fieldbus network architecture.

### 2.2. EtherCAT Operation Principle

EtherCAT technology breaks through the limit of other Ethernet solutions, without receiving Ethernet packets, decoding and replicating process data to net equipment. Based on Master-slave structure, master site launches control cycle and telegraph. Data frames traverse all slave equipments. According to the commands in the message, each equipment reads and writes matching sub data to appointed place of the passing data array. After data frames visit the last slave station of the whole system, it upwardly sends the processed data as uplink telegraph to the host station. Schematic structure of system is shown in Figure 1.

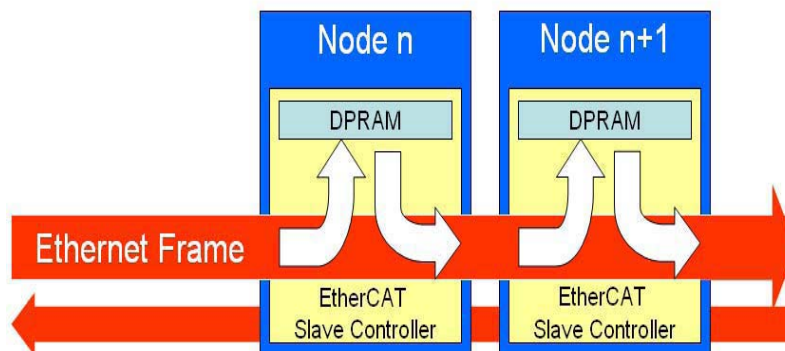


Figure1. The Sketch of EtherCAT Fieldbus

**Distributed Clock Technology:** The Distributed Clock is designed to synchronize distributed motion controller. The use of DC in systems where the devices are located in

different places must care the signal propagation delay from the timing source to the device and synchronize the distributed clock. The DC unit of EtherCAT slave controllers supports the clock synchronization between slaves. For synchronizing systems, the master assigns the first slave supporting DC as the Reference Clock which all other slaves will follow [13].

**Bandwidth utilization and performance:** EtherCAT populates the data of many devices in both the input and output direction within one Ethernet frame. The actual bandwidth utilization of the media increases to over 90%. The full-duplex features of 100BaseTX are fully utilized, so that effective data rates of >100 Mbit/s can be achieved. EtherCAT is not only substantially faster than traditional fieldbus systems, but is also considered to be the fastest among the industrial Ethernet solutions. Typical EtherCAT cycle times are 50-250  $\mu$ s, while traditional fieldbus systems take 5-15 ms for an update [14].

### 2.3. Excellent Features of EtherCAT

EtherCAT incorporates many excellent features especially in case of Large-scale networked control [15-16].

**Extremely fast:** A dedicated interface chip makes sure that the telegram passing through the slave station is read and written in a few nanoseconds.

**Flexible topology structure:** EtherCAT supports almost any topology including Line, tree or star.

**Extremely accurate synchronization:** A very precise network-wide time base with a jitter of significantly less than 1 microsecond is available.

**Simplest hardware:** One of the main advantages of Ether-CAT is that it doesn't require any special hardware on the master computer; a standard Ethernet card is all that is required.

## 3. Optimized Design of Soft Logic Control Model

### 3.1. Analysis of Various Control Model

**Traditional hard PLC control:** Although the traditional hard PLC controller is reliable, the unchangeable hardware structure shows disadvantages of poor interoperability and bad flexibility in solving large-scale distributed control problems. Because of its bad performance in clustered-control, single function, bad interface openness etc, it isn't suitable for large-scale distributed control. For example, though SIEMENS TCPU is exclusively applied motion control, one TCPU at most controls 32 axes.

**Industrial PC control:** Because industrial PC is based on PC control platforms, in contrast with PLC, it takes on strong accounting capability, rich interfaces, strong commonality. Unfortunately most of them run Windows operating system which is based on message transmission mechanism. Thus the uncertainty of message transmission can not meet the requirements of real-time motion control.

**Soft logic control:** Soft logic control based on PC control platform owns advantages of PLC and PC. The number of motors in soft logical architecture can be changed freely. In case of more than thousands of motors control, it is cost-effective. For example the soft logic controller of Beckhoff company in Germany can control 255 motors which offers high performance in clustered-control, network structure, interface openness. After the above analysis, this paper adopts soft logic controller in the new solution.

### 3.2. Features of Soft Logic Control

Soft logic controller consists of Programming system and Operating system. Programming system is used to develop user's program. Operating system is the core of soft PLC, which is mainly comprised by the I/O interface, error manager etc. Error manager is responsible for real-time detection software and hardware errors, which can greatly improve the maintainability of the system [17].

The open architecture of PC platforms is applied in soft logic control and one or more software virtual PLC real-time control engines run in real-time operating system. Thus the system can not only finish hard PLC logical control function, but also makes up for deficiency of hard PLC in process control and network communication. Compared with traditional PLC, Soft logic is more suitable for large-scale control.

**3.3. Soft Logic Control Architecture**

The soft logic control is made up of three parts: user system, communication Interface, Real-time system, which is shown in Figure 2. Monitoring software (HMI, OCX, DLL, OPC) runs in User layer. Soft logic real-time software (Virtual PLC, NC, CNC) is embedded in Real-time system.

Both monitoring software in user layer and real-time control software in kernel layer run in embedded PC platforms. Soft logic real-time operating system is based on client and server model. As the client, monitoring software or third-party software exchanges information with the ADS router through DLL, OCX control or OPC interface. The router conveys control commands to soft PLC/NC modules or IO module in real-time kernel layer. Finally the server modules such as soft PLC or NC control terminal equipments by IO mapping mechanism.

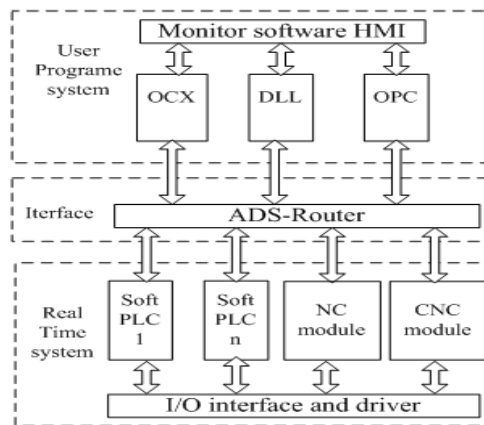


Figure 2. The Architecture of Soft Logic Control

**4. Novel Optimized Control Solution**

After the above analysis, EtherCAT fieldbus and soft logic controller was effectively optimized in the new solution. The topology architecture of the new solution is briefly shown in Figure 3. Two layers of network control structure constitute the new solution: Control center and five distributed control node are on the top networked layer; Motor drive terminals and I/O devices etc organize the bottom EtherCAT fieldbus layer which is shown in Figure 4. After optimizing, one networked control center can control 220 stepper motors, greatly improving the clustered- control capability of system. Meanwhile the extraordinary real-time performance of EtherCAT assures that it can meet the need of high speed motion control.

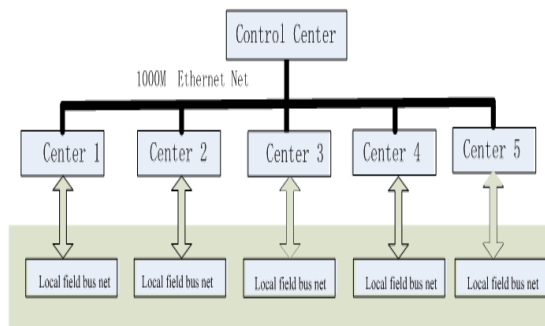


Figure 3. The Networked Topology of Control System

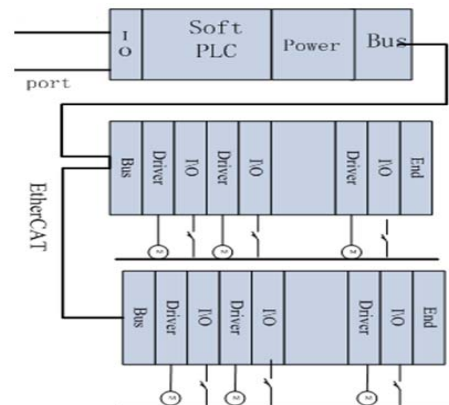


Figure 4. The EtherCAT Fieldbus Architecture

## 5. Evaluation of Optimized Solution

### 5.1. Performance Comparison of each Solution

There is an index comparison of each control solution performance, which is show in Table 1. It shows that the optimized control solution is better than others.

### 5.2. Evaluation of Optimized Solution

In the following, We will briefly evaluate the new solution.

**Real-time performance of EtherCAT:** In condition of controlling 40 motors, 2000 digital signal Input/Output, 200 analog signal input/output, Figure 5 showed that EtherCAT cycle time is the shortest one (276 $\mu$ s). Because of the high-efficiency of EtherCAT communication mechanism, the real-time performance is significantly better than other fieldbus.

**Clustered-control performance of soft logic:** Due to the soft logic incorporating several software real-time engines, it can mostly control 255 motors. The test has shown that the number of controlled motors by soft logic is far more than the other control model such as traditional PC or PLC.

Table 1. Comparison of Performance index

Performance index	ProfiBus scheme	ProfiNet scheme	EtherCAT scheme
Control model	Hard PLC	Hard PLC	Soft Logic
Filedbus type	Profibus	PROFINET	EtherCAT
Real time	<10ms	<800us	<300us
Motor number of each unit	2	32	255
Maintainability	bad	good	best
Reliability	poor	good	best

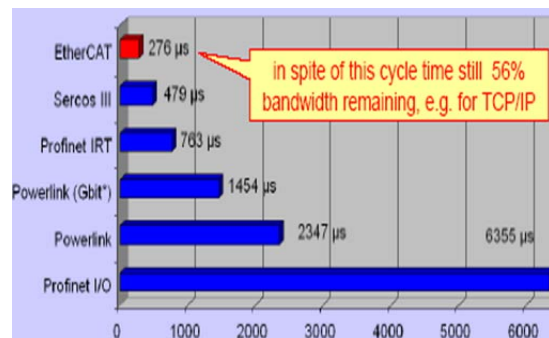


Figure 5. The Real-time Performance of Fieldbus

## 6. Conclusion

In summary, the existing solutions are not suitable for large-scale networked control, so the paper proposed a new optimized solution combining EtherCAT network structure and soft logic control technology. They are suitable for networked control in principle and characteristics. Therefore, the optimized solution concisely and effectively solves the large-scale distributed control problem. At present, this method has been applied successfully in the specific project. The practice shows that it takes on superiority in system integration and flexible structure, engineering practicability. The novel solution reduces the complexity in wiring connections, and provides ease in maintenance and agility etc. So it has the significance of being used as reference in solving similar network distributed control problem.

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