Design and Implementation of Fully Integrated Automation Scheme Based on Heterogeneous Field-bus Network

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Abstract. In view of the current situation of coexistence of various fieldbus protocols, the paper presents a totally integrated automation scheme based on Ethernet. The Ethernet technology can integrate the information of different field devices in the enterprise, and realize the unified data management, communication, programming and configuration. The paper systematically expounds the concept of totally integrated automation, realize totally integrated automation scheme based on Ethernet communication technology by designing protocol conversion gateway and applying to serial server. The solution is very suitable for information integration in enterprise, as the information exchange is realized at the device level, and the hardware design costs low.

Keywords: Integrated automation scheme; Ethernet technology; Heterogeneous Field-bus Network.

1. Introduction
TIA (totally integrated automation) originated in Europe. At that time, the introduction of TIA was called a technological revolution, which was highly praised in industry. After several years development, TIA continues to grow, and now it can be widely used in industrial production. The idea of totally integrated automation is to use one system or one automation platform to complete all the functions that originally were completed by combining multiple systems. This solution can greatly simplify the structure of the system, reduce a large number of interface components, and overcome the boundaries between the upper computer and industrial controller, between continuous control and logic control, between centralized and decentralized. With the rapid development of Ethernet technology, Ethernet technology is gradually applied to the field of industrial control. The TIA designed by Ethernet communication technology will greatly enhance the core competitiveness of relevant enterprises.

2. Fully Integrated Automation Solution
TIA solution can provide a unified technical environment for all automation applications. Its main advantages include unified data management, unified configuration and programming environment, unified communication and high openness.

The TIA technology adopts a global unified database, and all industrial software obtains data from a global shared unified database. This unified database and unified data management mechanism make all system information stored in a database and only need to be input once. It can not only reduce the repeated input of data, but also reduce the error rate and improve the efficiency. System diagnosis efficiency, enhance the integrity of the system and the accuracy of information, and provide technical support for the safe and stable operation of the plant.
The TIA also realizes the coordinated communication from the field level, the control level to the
management level. Its main features are unified configuration, integrated routing function in the
system, integrated system diagnosis and reporting function. All kinds of networks in the totally
integrated automation system can be interconnected, and the integrated routing function can easily
realize cross network download, diagnosis and other functions, making the installation and debugging
of the whole system easier.

Standardized and open architecture is the main feature of totally integrated automation system. It is
open to all types of field equipment, open to office system, supports Internet and open to new
automation structure. Totally integrated automation system is connected with office automation
application and Internet / Intranet by Ethernet TCP / IP protocol. Siemens TIA uses OPC as the
standard interface to access process data. By this interface, it is easy to establish the connection
between all PC automation systems and office applications. It is possible by Internet technology to
remotely operate and monitor the factory at any location.

3. Heterogeneous Fieldbus Interconnection Scheme

Due to different application requirements, different kinds of bus devices are likely to be used in the
internal control network of the enterprise. Integration of these devices can be realized in the upper
computer, or be integrated into a field bus network. Obviously, the latter integration mode is cheaper
and easier to implement. This paper analyzes the latter mode, uses the protocol conversion gateway
from all kinds of Fieldbus to PROFIBUS-DP bus to realize the integration of different kinds of
Fieldbus devices in PROFIBUS network. It is a high cost-effective information integration mode.

In recent years, with the rapid development of computer networks and industrial control networks, a
large number of heterogeneous networks based on different protocols have been established to meet
the communication needs of various applications. Due to the incompatibility of various
communication network protocols, heterogeneous distributed networks can not interact with each
other. However, the development trend of information technology is to realize the value-added
communication services and applications through different kinds of communication structures and
network platforms, so we must try to realize the interconnection of various heterogeneous networks.

With the maturity of the international standards of OSI network architecture and communication
protocol, promote international standards and adopt unified agreements gradually becomes a possible
solution. Although this scheme can completely solve the problem of interconnection between
heterogeneous networks, it is unrealistic to adopt this scheme on the premise that a large number of
non OSI networks have been established. And with the development of standardization network
technology, the network communication protocol will inevitably produce diversification. So it is
inevitable to consider the interconnection communication of heterogeneous networks. Protocol
transformation is proposed to solve this problem. It can coordinate different network protocols and
help to complete the communication services between heterogeneous networks, as a result, it can solve
the incompatibility between various communication networks and the problem that users of
heterogeneous distributed networks cannot interact with each other.

Because most of the protocol definitions in fieldbus layers are different, the interconnection between
them can only be realized by protocol conversion gateway. Protocol conversion gateway can solve the
incompatibility between protocols and realize the interaction between two interconnected networks.

By establishing a protocol transformation between two known protocols, it receives information from
one protocol and transfers it to another protocol after interpretation, so as to realize the information
exchange of incompatible network boundaries.

There are three kinds of protocol conversion methods that can be used for protocol conversion
gateway:

(1) Service level conversion: generate gateway from program service description;
(2) Protocol level conversion: generate gateway from protocol description, it is unable to complete service
description, but can be coordinated at protocol information level;
(3) Hybrid conversion: it is a combination of the above two methods, which not only requires the input of
protocol description, but also needs to input program service description.
In order to improve the efficiency of protocol conversion, the hybrid protocol conversion method should be used to design the fieldbus protocol conversion gateway. The open structure of fieldbus protocol determines the feasibility of researching protocol conversion gateway. All kinds of fieldbus protocol chips make the design of gateway hardware relatively simple. The relationship between fieldbus protocol and communication service can be described in two abstract layers: in the high-level abstract layer, the communication system, as a service provider, provides specific communication services to users; in the low-level abstract layer, the communication system is regarded as several cooperative protocol entities (Protocol Entities PES) is used to exchange protocol information, i.e. protocol data units PDUs. Protocol entities exchange information on reliable communication media according to the rule of first in, first out. The fieldbus protocol conversion gateway will transfer the high-level information layer by layer down, through the lowest channel, to another fieldbus device, and then rise layer by layer until it reaches the peer layer of information transmission.

Taking PROFIBUS-DP bus and MODBUS bus as examples, both of them can use RS-485 communication standard in physical layer, but their data link layer and user interface / application layer are totally different, so they are two heterogeneous networks. Protocol conversion needs to be carried out in a hierarchical way, from the lower layer to the higher layer. The lower layer supports the higher layer, and the higher layer calls the lower layer. After the connection of the lower layer is disconnected, the connection of the higher layer is also disconnected, but the disconnection of the higher layer does not affect the lower layer. The communication model converted from PROFIBUS-DP to Modbus protocol can be constructed as follows (Figure 1):

![Figure 1. PROFIBUS-DP to MODBUS protocol conversion gateway model.](image)
mechanism, and connects to PROFIBUS-DP bus through high-speed optocoupler and bus driver. The shared RAM is provided by the 1.5k dual port RAM integrated in the protocol chip ASPC2, which can be addressed by both ASPC2 and STM32F407. The structure of gateway circuit is designed as follows:

![Gateway Circuit Structure](image)

**Figure 2.** Gateway Circuit Structure.

4. Interconnection Scheme of Fieldbus and Ethernet

Industrial Ethernet is a widely accepted communication standard in the industry. The openness of the totally integrated automation scheme is also reflected in the interconnection with Ethernet. This paper discusses two low-cost interconnection schemes of fieldbus and Ethernet: one is device level interconnection scheme, which uses protocol conversion gateway to realize interconnection between fieldbus device and Ethernet device; the other is to realize interconnection in upper computer, which maps Siemens S7-300 through serial port server. The MPI communication port of CPU uses MCGS industrial control software to monitor the port to get field data.

4.1. Equipment Level Interconnection Scheme

According to the different structure of fieldbus, the protocol conversion gateway between fieldbus and Ethernet can be divided into two types: one-way protocol conversion gateway and two-way protocol conversion gateway. In the master-slave fieldbus network, only the master station is the active node, so the protocol conversion gateway between this kind of fieldbus and Ethernet is unidirectional; in the non master-slave fieldbus network, each node can be the active node, so the protocol conversion gateway between this kind of fieldbus and Ethernet is bidirectional.

No matter one-way or two-way protocol conversion gateway, there are two directions of data transmission. For the one-way protocol conversion gateway, the data transmitted includes the request data from the master station and the response data from the slave device; for the two-way protocol conversion gateway, the data transmitted includes the request data and the response data between the devices. According to the analysis in the previous section, the protocol conversion gateway of fieldbus device and Ethernet device should be constructed by the mixed protocol conversion method, and the communication model of the gateway is shown in Figure 3. Protocol data is transferred layer by layer in the gateway along the dotted line in the figure.
The main task of the protocol conversion gateway is to explain the communication protocols of the two interconnected networks and to realize the exchange and forwarding of protocol data. Therefore, the functions that the field bus and Ethernet protocol conversion gateway must have include: the receiving and sending of field bus data and Ethernet data, the forwarding of protocol data and the management and scheduling of the communication tasks of the gateway. The function of receiving and sending fieldbus data message and Ethernet data frame is realized by special communication interface circuit. The more efficient design scheme is to design fieldbus communication interface and Ethernet communication interface respectively by using fieldbus protocol chip and microprocessor specially used for Ethernet communication. The hardware circuit of gateway can be divided into three parts: PROFIBUS-DP communication interface circuit, Ethernet interface circuit and data forwarding circuit. The internal structure of the gateway is as follows:

PROFIBUS-DP communication interface circuit is mainly composed of microprocessor 89C52 and protocol chip SPC3; Ethernet interface circuit is mainly composed of embedded processor S3C4510B (ARM7 core) and Ethernet physical layer chip RTL8201; the core component of data forwarding circuit is dual port RAM chip IDT7134. Because S3C4510B chip is integrated Ethernet MAC controller with IEEE 802.3, the embedded processor can simplify the design of Ethernet interface circuit. Because the design of PROFIBUS-DP communication interface circuit and Ethernet interface circuit is relatively mature, only the design of data forwarding circuit is introduced here. The data forwarding circuit is responsible for sending the PROFIBUS-DP master data received by the gateway to the application layer of the Ethernet communication stack, or sending the data received by the gateway from the Ethernet device to the PROFIBUS-DP user interface. The core part of the data forwarding circuit is the dual port RAM chip IDT7134, which is a high-speed 4kbytes dual port static.
RAM chip. It provides two independent ports with independent control, address and I/O pins, and allows independent asynchronous read-write access to any address of memory. The automatic power management feature is controlled by the CE pin, allowing every port circuit on the chip to enter a very low power mode.

![Data Forwarding Circuit](image5)

**Figure 5.** Data Forwarding Circuit.

The 1500 units of 0x0000 ~ 0x05DB in the storage unit of dual port RAM are used to store data messages of Ethernet equipment, and the 250 units of 0x0600~0x06F9 are used to store data messages from PROFIBUS-DP bus. According to the circuit structure shown in Figure 5, the mapping address of dual port RAM in the microprocessor responsible for Ethernet communication is 0x7000 ~ 0x7FFF, and in the microprocessor responsible for PROFIBUS communication is 0x2000 ~ 0x2FFF. The 0x0FFE and 0x0FFF units in the chip are used for interrupt arbitration. When the right port writes to the memory address 0x0FFE, the interrupt flag of the left port is declared, and the left port must clear the interrupt by accessing the 0x0FFE memory address; similarly, when the left port writes to the memory address 0x0FFF, the right port flag is declared, and the left port must clear the interrupt by accessing the 0x0FFF memory address.

4.2. Upper Computer Interconnection Scheme

An alternative scheme of interconnection between Siemens PLC and Ethernet using serial port server is designed. Compared with the scheme using Siemens CP343-1 Ethernet communication module, the implementation cost of the scheme is less than 1/5 of the latter.

![Interconnection between Siemens PLC and Ethernet](image6)

**Figure 6.** Interconnection between Siemens PLC and Ethernet.

The system designed by selecting CPU313C-2DP of Siemens 300 series as CPU, CPU313C-4A as DC power supply, and PROFIBUS-DP communication I/O module developed by ourselves. When the system is connected, it needs to connect the CPU and serial server of Siemens PLC system by MPI communication cable, which is Siemens special programming cable. The serial server of IEIDATA company IECOM232_485NET-4101G is selected as the serial server, its IP address is set to 192.168.127.253, the IP address of the industrial computer is set to 192.168.127.1, which is in the same network segment with the serial port server. The industrial computer needs to install MCGS industrial control software (version 6.2). The connection scheme of the whole experimental system is as follows:
Figure 7. System Connection Scheme.
The upper computer monitoring program is designed by using MCGS industrial control software, which needs to add the S7-300 parent device and S7-300 sub device drivers suitable for Siemens S7-300 series. The remote monitoring of Siemens I/O module can be realized by operating the monitoring program through Ethernet.

5. The Realization of Fully Integrated Automation
Similarly, by the scheme of fieldbus protocol conversion gateway described in this paper, the protocol conversion gateway from PROFIBUS-DP bus to Ethernet, from PROFIBUS-DP bus to MODBUS, from PROFIBUS-DP bus to CAN bus and from PROFIBUS-DP bus to HART bus can also be designed. With these gateways, the embedded Ethernet device, MODBUS device, CAN device and HART device can be integrated into one PROFIBUS-DP network, it is an automatic integration of distributed I/O devices. For automation process, PROFIBUS-PA and PROFIBUS-DP are connected by cable coupler and integrated in PROFIBUS bus network. The connection scheme is shown in Figure 8.

Figure 8. Connection scheme of fully integrated automation system.
By integrating the distributed I/O equipment and process automation equipment into Ethernet communication network, after being authorized, the local monitoring machine and the network synchronous monitoring machine can realize the monitoring and management of all field devices, and then realize the information integration of various devices in the enterprise internal control network based on the Ethernet communication technology.
6. Conclusion
Due to the limitation of buffer capacity and PROFIBUS communication rate in the gateway, the number of heterogeneous fieldbus devices connected by the protocol conversion gateway cannot exceed 126. However, the totally integrated automation scheme shown in Figure 8 is applicable to the medium-sized automation integration. Because this scheme is a kind of information integration based on device level, its real-time performance is better than that of information integration in upper computer. In addition, the totally integrated automation scheme also has the advantage of low information integration cost. It only needs to design protocol conversion gateway, and all kinds of original field equipment can continue to use. At present, the totally integrated automation scheme implemented according to the scheme has been put into trial operation in an industrial kiln production line, integrating PROFIBUS devices, MODBUS devices and Ethernet devices. The system is stable and reliable, and has achieved good results.

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