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INTRODUCTION OF ETHERNET-BASED FIELD NETWORKS TO INTER-DEVICE COMMUNICATION FOR RIBF CONTROL SYSTEM

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Abstract

Internet Protocol (IP) networks are widely used to remotely control measurement instruments and controllers. In addition to proprietary protocols, common commands such as the standard commands for programmable instruments (SCPI) are used by manufacturers of measuring instruments. Many IP-network-based devices have been used in RIBF control systems constructed using the experimental physics and industrial control system (EPICS); these are commercial devices designed and developed independently. EPICS input/output controllers (IOCs) usually establish socket communications to send commands to IP-network-based devices. However, in the RIBF control system, reconnection between the EPICS IOC and the device is often not established after the loss of socket communication due to an unexpected power failure of the device or network switch. In this case, it is often difficult to determine whether the socket connection to the EPICS IOC is broken even after checking the communication by pinging. Using Ethernet as the field network in the physical layer between the device and EPICS IOC can solve these problems. Therefore, we are considering the introduction of field networks such as EtherCAT and Ethernet/IP, which use Ethernet in the physical layer. In the implementation of the prototype system, EPICS IOCs and devices are connected via EtherCAT and Soft PLCs are run on the machine running EPICS IOCs for sequence control.

INTRODUCTION

The control system of the RIBF accelerator facility is based on the experimental physics and industrial control system (EPICS). When it was first operated in a facility in 2002, the EPICS input/output controller (IOC) installed in the VME CPU used the VME bus as an interface between devices and was accessed via the device driver [1]. Later, with the introduction of the EPICS R3.14 series, bus connections and IP protocols were used for inter-device communication between the devices and the EPICS IOC [2]. Currently, the RIBF control system uses N-DIM, an internet protocol (IP) network-based device developed in-house, and PLCs from MELSEC, OMRON, FA-M3, and other companies that are connected via Ethernet and operated with device support using NetDev [3] and AsynDriver [4, 5]. Measurement devices such as digital multimeters are utilized to monitor the beam currents. In many cases, measurement instruments use ASCII-based communication commands called standard commands for programmable instruments (SCPIs) as the presentation layer protocol. They are operated using a Stream Device [6] with EPICS device support.

Generally, Ethernet, which is a physical layer and data link layer in the OSI reference model, is very convenient and easy to handle, and is currently the standard equipment in devices from many manufacturers. These devices and IOCs typically communicate through asynchronous socket connections. However, after a power failure, a reboot owing to device failure, or an unexpected power loss of a switch, the socket connection is often not restored, and the EPICS IOC must be restarted for reconnection, interrupting the smooth operation of the accelerator. In addition, the RIBF upgrade plan [7] is expected to support applications that require a fast response time, which is not possible with IP networks, while maintaining the convenience of Ethernet as a protocol. The introduction of Ethernet-based field networks to RIBF control system addresses these concerns.

COMPARISON OF FIELD NETWORKS

Network switches for the control system are typically placed in computer, experimental, and accelerator rooms. An advantage of IP-network-based devices is that they require minimal installation of Ethernet cables. Conversely, they may be less reliable owing to their low real-time performance and slow I/O communication. However, developing a new proprietary dedicated protocol, such as the NIO [8] used in the RIBF control system, would be expensive. Therefore, we considered Ethernet-based field networks and general-purpose protocols, such as EtherCAT [9], FL-net [10], and EtherNet/IP [11].

Among these protocols, the FL-net-based interlock system has successfully been constructed for the injection of the RIKEN ring cyclotron [12]. However, FL-net requires a dedicated network and cannot be mixed with the control network, thereby reducing its convenience. EtherNet/IP is highly convenient because it does not require a dedicated network, can be connected directly to a regular IP network switch, and requires minimal Ethernet cabling.

In addition to FL-net, EtherCAT requires a dedicated network, and because it is not possible to mix TCP/IP with the network, a new cable must be installed. However, because EtherCAT master–slave communication is faster than that of general-purpose protocols, a faster response can be achieved than with EtherNet/IP and FL-net; it also enables high real-time control.

In the RIBF upgrade plan [7], accelerators have become more sophisticated, the beam intensity has increased, and high-speed interlock signal output and highly accurate synchronization control have become necessary. Therefore, we have developed a prototype system using EtherCAT. We have also constructed an EtherNet/IP prototype system which can be mixed with IP network-based switches, minimizing wiring work and providing high convenience.

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ETHERNET/IP-BASED SYSTEM

Protocol

EtherNet/IP is a widely used network in Ethernet-based industrial applications. Diverse industrial devices use this network, which is overseen as an open standard by the Open DeviceNet Vendor Association (ODVA) [13]. EtherNet/IP is interoperable with traditional Ethernet and shares the same physical layer, including the frame structure, connectors, and cables, and is compatible with TCP/IP. In addition, it employs the Common Industrial Protocol (CIP) in the application layer, allowing for general-purpose network switches that are compatible with other IP network-based protocols, cost-effective wiring, and relatively high real-time performance.

Prototype System with EPICS

EtherNet/IP is a candidate protocol for replacing the old electromagnet power-supply control in the RIBF [14]. Because EtherNet/IP can be mixed with IP networks despite being a field network, it can be used not only as a protocol for electromagnet power control, but also for various other applications. An EtherNet/IP-based system typically comprises a scanner and adapters. The scanner is situated on the EPICS IOC side of the prototype system. Simultaneously, the adapter is installed onsite, as in accelerators or experimental rooms.

Figure 1 shows a chart of the prototype EPICS-based system. In this system, the scanner is constructed using FA-M3 series PLCs, and the dedicated module F3LN01-0N [15] facilitates inter-PLC communication with the devices via EtherNet/IP. For the interlock function, the sequence CPU F3SP76-7S [16] is installed in the first slot of the proposed system. In the second slot, a Linux CPU, F3RP71-1R [17], is installed at the EPICS IOC to provide a CA protocol for interfacing high-level applications. This system is characterized by a link register (W register) used as a standard in the FA-M3 PLC system, which serves as the I/O exchange between the adapter and the scanner, allowing development using familiar methods, especially device support, without awareness of the EtherNet/IP protocol.

ETHERCAT-BASED SYSTEM

EtherCAT Master

EtherCAT generally comprises a master and multiple slaves. The EtherCAT master, implemented as a prototype, utilizes SuperCD® by Interface Corporation (see Fig. 2). The specifications are listed in Table 1. SuperCD® is a compact edge computer designed for IoT, running a customized Linux (Interface Linux System 8) based on Debian 9.3 (stretch) as its operating system [18]. Interface Corporation's SuperCD® was partly chosen due to its track record as an input/output controller (IOC) based on LabVIEW for RIBF control systems [19]. The EtherCAT master functionality is also provided as software by the Interface Corporation and operated on this Linux system.

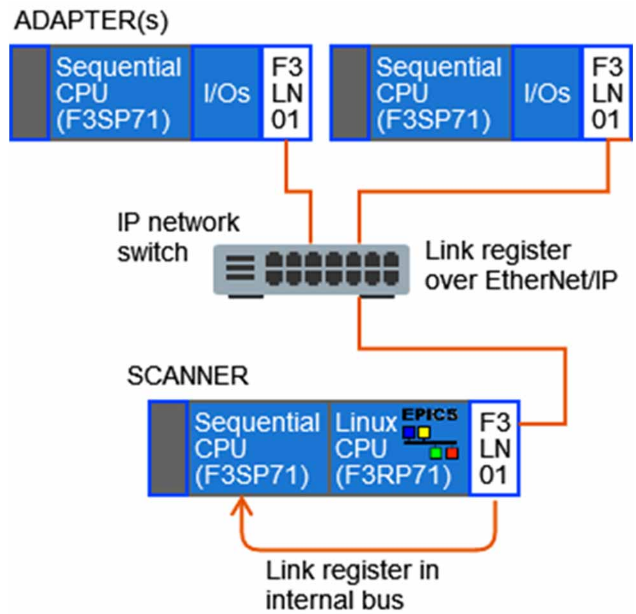

Figure 1: System chart of the prototype system, constructed with FA-M3 PLCs using EtherNET/IP as inter-device communication.

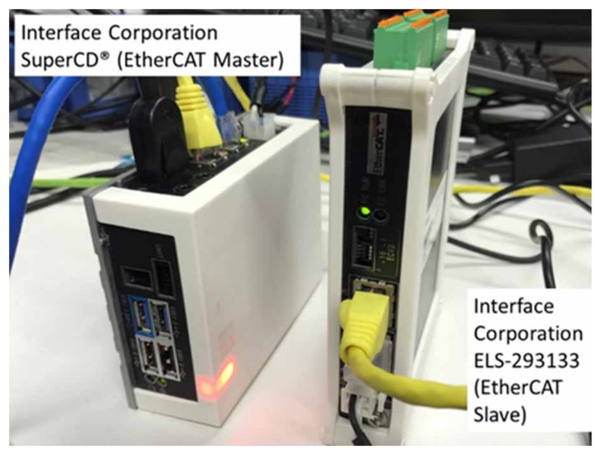

Figure 2: A photograph of a SuperCD® with embedded EPICS IOC and EtherCAT master being tested by connecting it to an EtherCAT slave. The right is ELS-293133 (DIO module) as the EtherCAT slave, and the left is EtherCAT master (SuperCD®).

Table 1: SuperCD® Hardware Specifications

	Processer	Intel Atom E3845 1.91 GHz
CPU	Number of cores	4
	Number of threads	4
Memory	4 GB	
Storage	SSD 32 GB	
LAN	2 ports (1000BASE-T)	

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EtherCAT Slave

As EtherCAT slaves, we implemented Interface Corporation's digital input/output (ELS-293133) and Yokogawa Electric Corporation's FA-M3 module F3LT02-0N. A photograph of the test environment is shown in Fig. 2. To use F3LT02-0N as an EtherCAT slave, as in connecting via FL-net, it is necessary to allocate link registers to PDO auto-refresh in the "FA Link/FL-net system settings" on the sequence CPU side using WideField3 [20].

In this system, the transmission area from the slave using F3LT02-0N to the master is designated as W0001, and the data reception area from the master to the slave is designated as W4097. Using these link registers, the EtherCAT master sends and receives instructions and data to and from the PLC CPU. However, data exchange between EtherCAT slaves requires intermediation through the master, such as Slave 1 -> Master -> Slave 2.

Python Interface

On the EtherCAT master, all data access to the slaves and the retrieval of the master state are handled through object variables. For instance, if the link register W0001 of the F3LT02-0N is defined in the ENI file as the mapping "TxPDO-Map00," in this system, it is represented as "ID1002_Read-4000". The development environment provided by Interface Corporation includes a library. Accessing this object variable through the library lowers the development threshold in C and Python.

EPICS Device Support

The EtherCAT EPICS device support was developed using PyDevice [21], an EPICS device for Python interpreters which allows Python functions to be called from C-based Soft IOCs and connects them to the EPICS database. Using PyDevice, the threshold for developing the EPICS device support for the EtherCAT prototype system was significantly lowered. Examples of EPICS device support for retrieving the value of the link register W0001 for the EtherCAT slave F3LT02-0N are presented in Listing 1, and examples from the EPICS database are shown in Listing 2.

Listing 1: Example of EPICS Device Support Written in Python, pydevEtherCAT.py

```
import sys, os
sys.path.append(os.path.join('/usr/share/inter-
face/CS/python/', 'lib'))
import ifcsm

def Read(ObjectName):
    ObjectHandle = ifcsm.ifcsmGetObjectHandle(Object-
Name)
    Ret, _val_ = ifcsm.ifcsmRead(ObjectHandle, 0, 1)
    if Ret < 0:
        print("ifcsmRead() failed (%s)" % ObjectName)
        Errno = ifcsm.ifcsmGetErrno()
        print("Errno = %Xh" % Errno)
    else:
        return _val_[0]
```

Listing 2: Example of EPICS Record Calling the Device Support Using PyDevice from the EPICS Database

```
record(longin,"PyDev:EtherCAT:ID1_DI1-8") {
  field(SCAN,".1 second")
  field(DTYP,"pydev")
  field(INP,"@pydevEtherCAT.Read('ID1_DI1-8')")
}
```

Results

The process data communication cycle achievable with SuperCD® for EtherCAT master is as fast as 100 µs and this cycle was effectively achieved with a slave count of 2. Accessing the EtherCAT master through the Python-based device support from the IOC and controlling the EtherCAT slaves worked smoothly. When the cable connecting the EtherCAT master and slaves was unplugged to intentionally create a disconnected state, network errors are detected, and higher-level clients can retrieve this information. In addition, it was possible to monitor the actual number of EtherCAT slaves accessed. A screenshot of the test GUI is shown in Fig. 3.

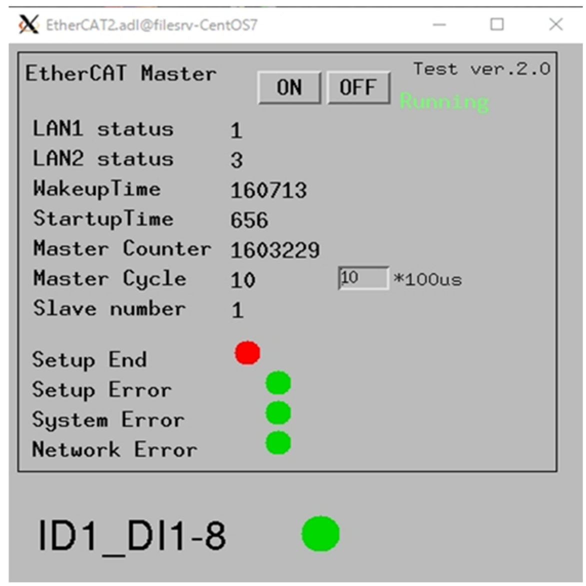

Figure 3: Screenshot of GUI constructed by MEDM. It monitors EtherCAT master information via EPICS channel access.

SOFTWARE PLC WITH ETHERCAT

In the EtherNet/IP prototype system, the adapter is equipped with a Linux CPU, F3RP71-1R, and a sequence CPU, F3SP71-4S, resulting in a multi-CPU configuration. Therefore, the I/O information of the scanners collected by the adapter can be sequenced by the F3SP71-4S such that processing can be achieved in the order of several milliseconds. However, data exchange between EtherCAT slaves is via the EtherCAT master; if the I/Os are processed in an upper layer such as an EPICS sequencer [22] or EPICS database running on EPICS IOC, the performance of the 100 µs process data communication cycle cannot be fully utilized. Therefore, Interface Corporation is currently developing a software PLC that runs on this EtherCAT master, and we conduct an operation test on the beta version of the software PLC.

SuperCD®, the EtherCAT master implemented in this system, has a 4-core CPU, and the EtherCAT master process occupies one core. Furthermore, the Software PLC process occupies only one of the four cores. We confirm that the EtherCAT master operates in a simple ladder

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sequence using the values received from the EtherCAT slave (see Fig. 4).

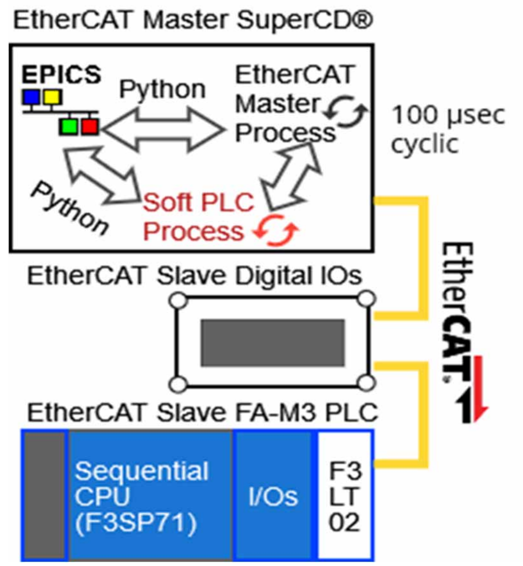

Figure 4: System chart of EtherCAT prototype system with the software PLC. The software PLC process also runs on SuperCD®, where the EtherCAT master process runs and receive the I/O data at cyclic intervals of 100 µs.

CONCLUSION

We focused on Ethernet-based field networks to improve the reliability and performance of devices, while taking advantage of the usefulness of Ethernet as a physical layer. We investigated the implementation method of EPICS for the field networks EtherCAT and EtherNet/IP. EtherNet/IP allows networks to coexist with the IP network; therefore, if an application requires a response of 10 ms or less, the cost of laying cables can be minimized. EtherCAT can operate with a process data communication cycle of 100 µs; therefore, it can be used in applications requiring high-speed processing, such as interlocks. To maximize the EtherCAT master's performance, the alpha version of the Software PLC from Interface Corporation will be needed. We currently plan to use these field networks as prototype replacements for IP-network-based devices, which have become deadstock.

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