Application Note

基于 PCIe 主站卡 C#搭建 IO 及电机控制应用

E 系列高速 IO 模块

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类别	内容
关键词	集中式远程 IO 从站、集中式步进电机驱动从站、 PCIe 转 EtherCAT 通讯卡
摘要	致远主站系列产品及 E 系列高速 IO 联调示例

修订历史

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目 录

1. 适用范围

本文介绍了致远电子开发的 PCIe-EtherCAT 主站卡与 E 系列集中式高速 IO 从站联调，搭建 IO 及电机控制的示例。

从站产品包括 E 系列集中式数字输入模块、数字输出模块以及步进电机控制模块等。

2. 基于 PCIe-EtherCAT 通讯卡 C#的搭建

PCIe-EtherCAT 通讯卡提供了 C/C++接口的 SDK 动态库。在 C#环境下，我们提供了对应的接口文件。用户只需要借助我们提供的接口文件导入 C/C++的 DLL 库，调用动态库提供的接口编写程序，就可以控制板卡运行 EtherCAT 主站。在主站程序中操作 PDO 数据、请求 SDO 读写命令，就可以控制从站设备，实现电机运动。

2.1 测试环境

主站设备：

- HPCIe-2E 通讯卡

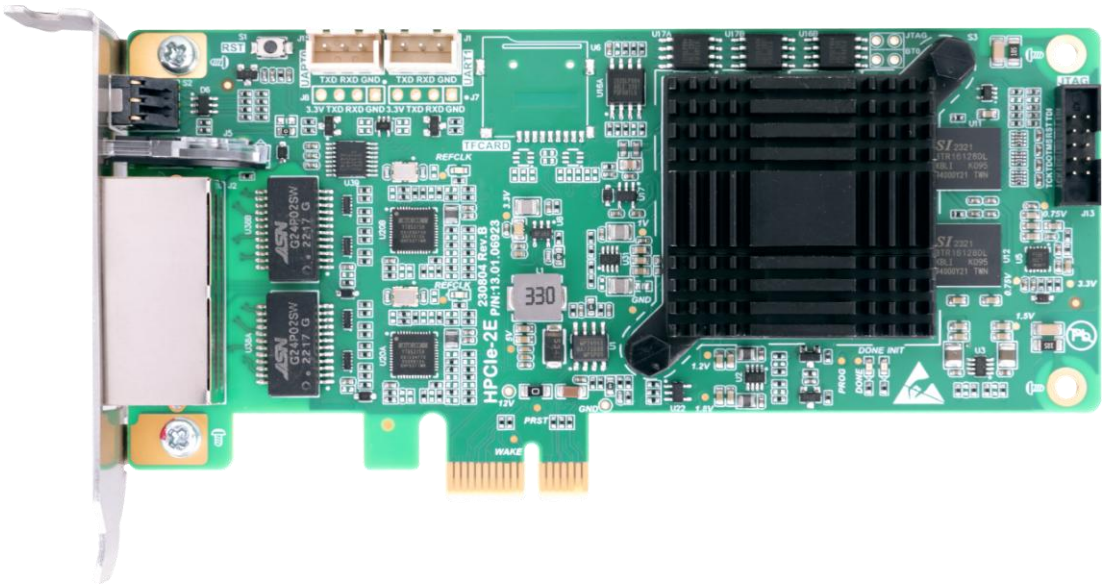

图 2.1 HPCIe-2E 主站通讯卡

从站设备:

- ZPT-8080 耦合器
- ZDM-E0016N 数字输出模块
- ZDM-E1600N 数字输入模块
- ZMTI-EF1200 步进电机驱动模块

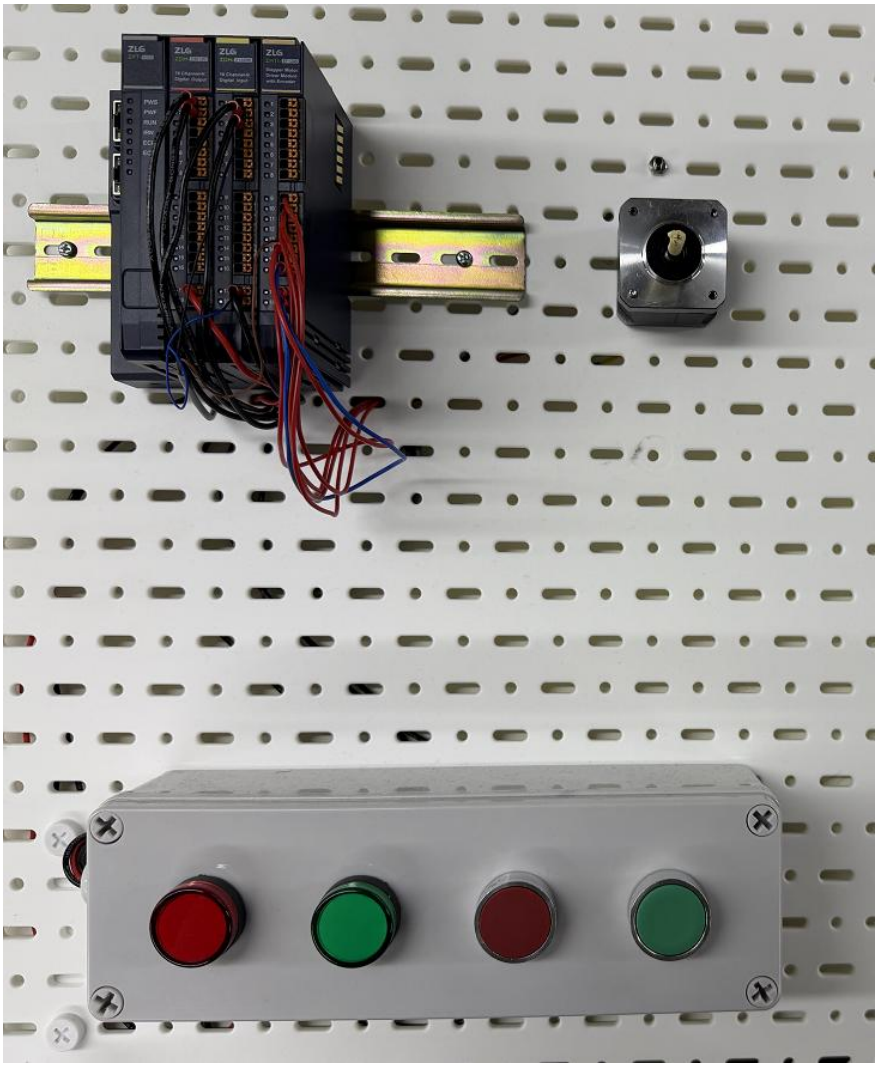

图 2.1　从站设备及其传感器执行器

其他硬件：

- 带 PCIe 卡槽的开发主机（Windows，可以同时作为配置和开发主机）
- 步进电机
- 指示灯（红、绿）
- 控制按钮（红、绿）
- 接近传感器
- 网线若干
- 24V 电源

软件环境：

- PCIe-EtherCAT 通讯卡的驱动程序，安装在开发主机上
- AWStudio 运动控制版 配置上位机
- Visual Studio 2015
- .Net framework 4.8 及以上版本

2.2 设备连接

将 HPCIe-2E 通讯卡插入到开发主机的 PCIe 卡槽中，开机，安装板卡驱动。

用网线连接 HPCIe-2E 通讯卡的 ECAT 口和 ZPT-8080 耦合器的 IN 口，将剩余模块顺次通过背板总线连接到耦合器。24V 电源分别 ZPT-8080 耦合器。

指示灯的信号从 ZDM-E0016N 数字输出模块的输出引脚引出。按钮的信号接入到 ZDM-E1600N 数字输入模块的输入引脚。电机的驱动线按次序接到 ZMTI-EF1200 的 9~12 的端口，如果有编码器信号也接到 ZMTI-EF1200 上。此外，ZMTI-EF1200 还需要额外的 1 路电源输入作为电机驱动电源。

2.3 运行效果

启动程序后，主站切换到 Operation 操作状态。电机系统进入停止状态未启动，绿灯闪烁。

按绿色运行键之后，电机开始转动，绿灯常亮。按红色停止键，电机停止转动，绿灯恢复闪烁。

用任意金属物体靠近传感器，电机系统进入紧急状态，电机停止转动，红灯常亮。按绿色运行键后，电机系统恢复运行。

2.4 ENI 文件生成

本节介绍通过 AWStudio 运动控制版配置上位机生成 ENI 文件。

2.4.1 新建解决方案

AWStudio 启动后默认没有解决方案，需要先新建或打开一个解决方案。

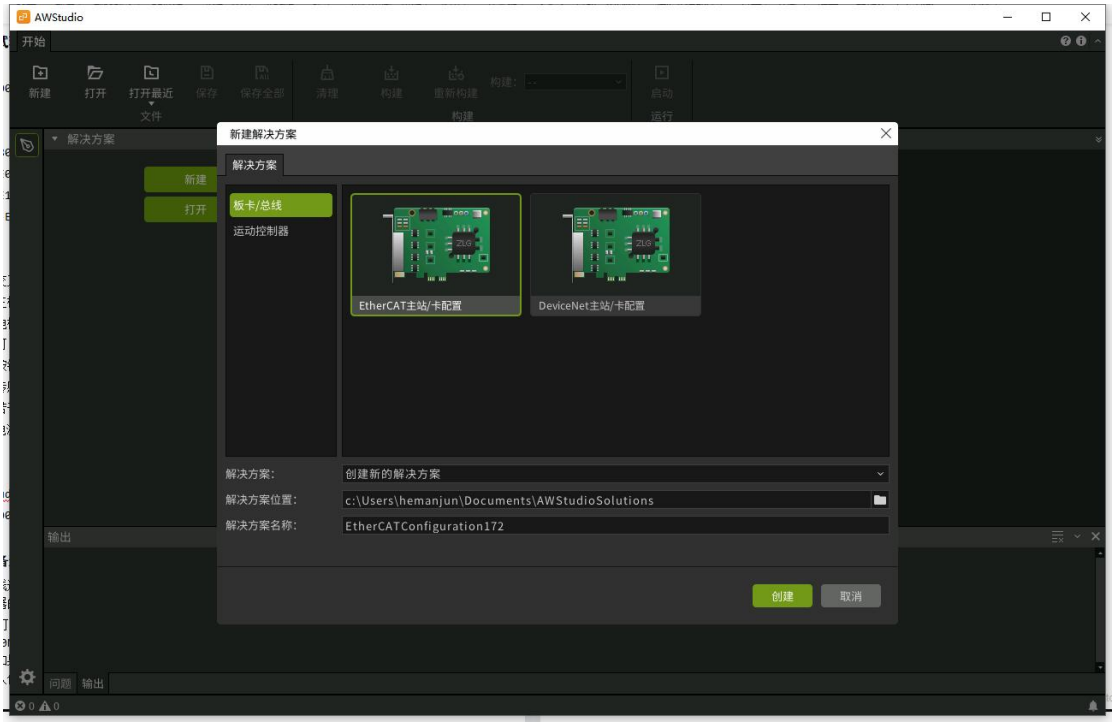

图 2.2 新建 EtherCAT 解决方案

2.4.2 添加从站

添加从站可以通过在线扫描或手动添加的方式。

图 2.3　拓扑扫描

添加从站后如图 2.4 所示。

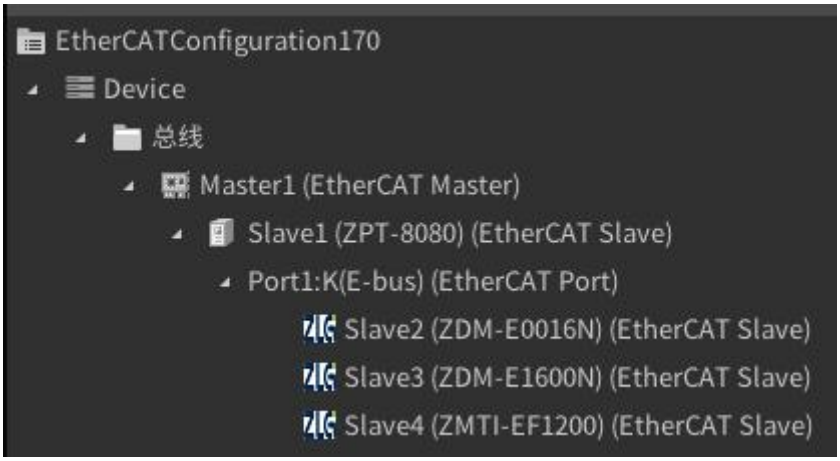

图 2.4　EtherCAT 网络拓扑

2.4.3 配置电机的 PDO 过程数据

双击从站 ZMTI-EF1200，打开“从站配置-变量页”，可以查看厂商 ESI 默认配置下的 PDO 变量，如图。默认变量不一定能满足我们的控制需求。ZMTC-EF1200 默认是 CSP 模式的过程变量。有需要时可以自行配置电机的 PDO 变量。

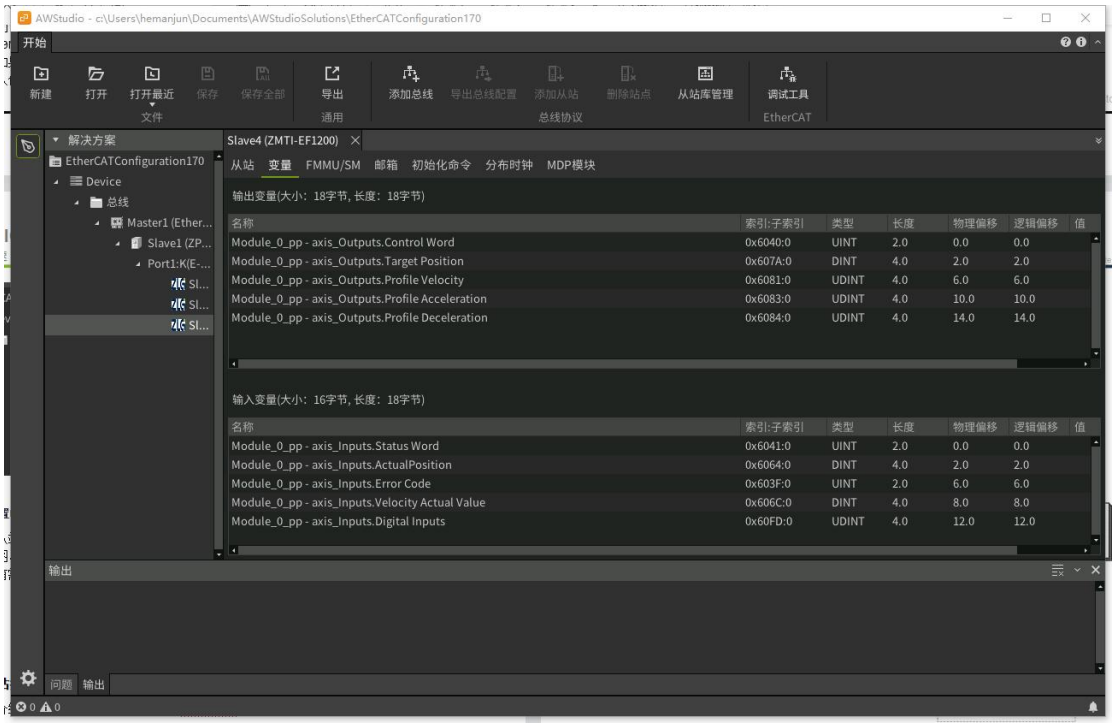

图 2.5　从站的 PDO 过程数据

打开“从站配置-MDP 模块”，可以看到画面分为两个区域，左边“插槽配置”为当前启用的配置项，右侧模块库为我们预定义的可用模块，可以看到是各模块是按 CiA402 电机控制模式去区分的。默认为 CSP 模式。

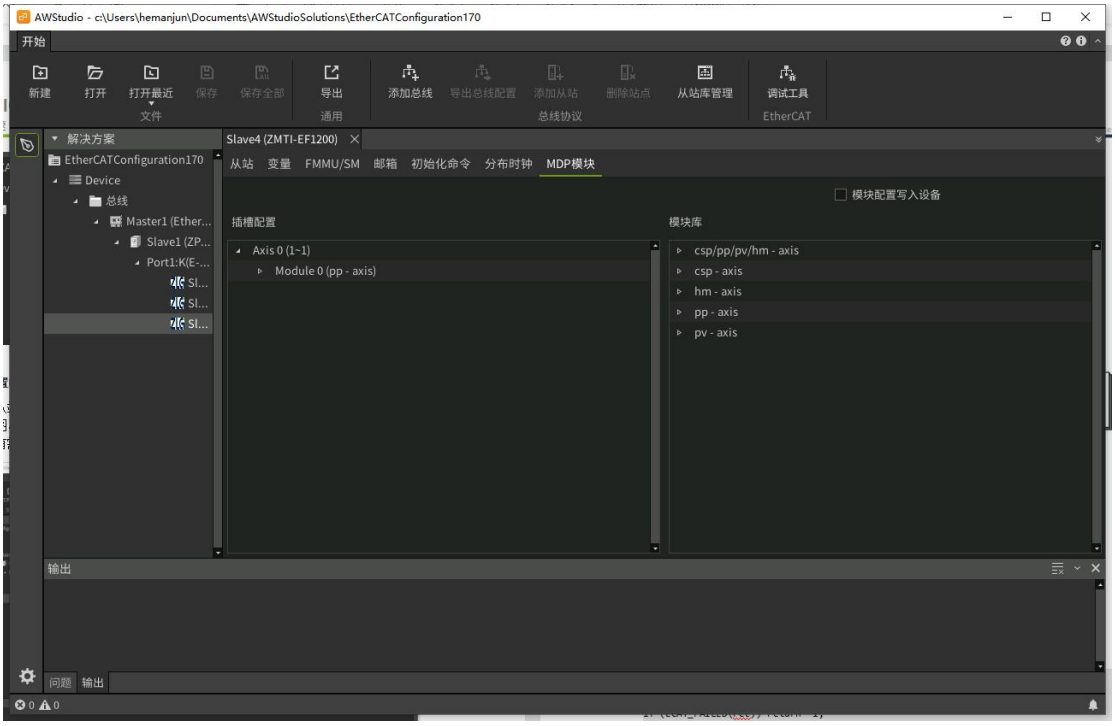

图 2.6　MDP 模块配置

2.4.4 导出 ENI

同样配置其他主站和从站参数，完成后导出 ENI 文件。

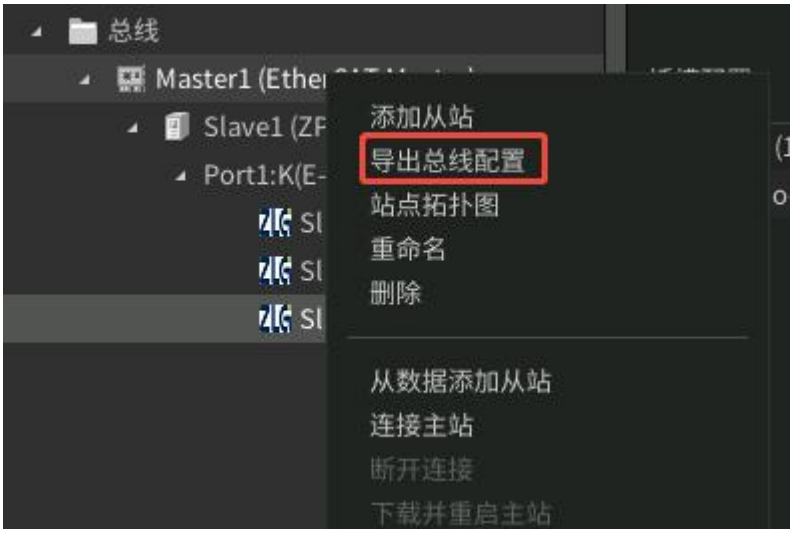

图 2.7　导出总线配置到 ENI 文件

2.5　过程数据 PDO

根据主站配置和网络拓扑结构，我们需要定义当前拓扑下使用的 PDO 数据结构。

打开“主站配置-变量”页，查看当前网络拓扑下的数据结构。

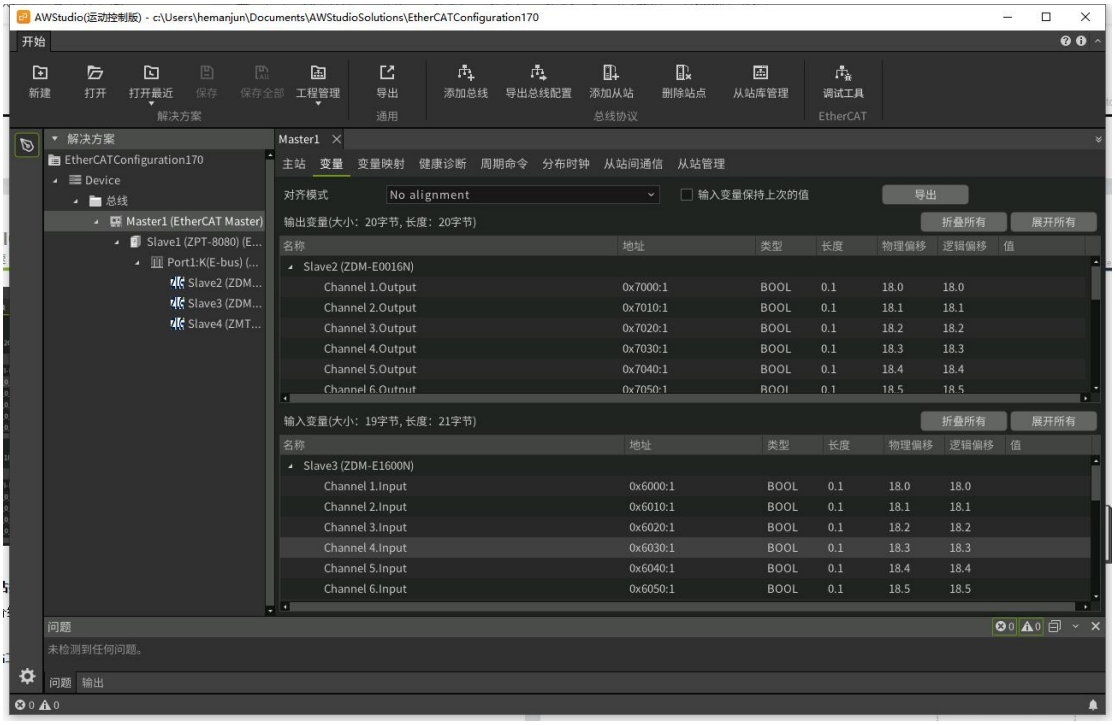

图 2.8　EtherCAT 总线拓扑的 PDO 过程数据

结合从站手册的定义，可以定义为以下的结构。

```
class servo_ctrl_word
{
    public servo_ctrl_word()
    {
        v = 0;
    }
    public UInt16 switch_on
    {
        get { return Uint16BitGet(v, 0); }
        set { Uint16BitSet(ref v, 0, value); }
    }
    public UInt16 enable_voltage
    {
        get { return Uint16BitGet(v, 1); }
        set { Uint16BitSet(ref v, 1, value); }
    }
    public UInt16 quick_stop
    {
        get { return Uint16BitGet(v, 2); }
        set { Uint16BitSet(ref v, 2, value); }
    }
    public UInt16 enable_operation
    {
        get { return Uint16BitGet(v, 3); }
        set { Uint16BitSet(ref v, 3, value); }
    }
    public UInt16 fault_reset
    {
        get { return Uint16BitGet(v, 7); }
        set { Uint16BitSet(ref v, 7, value); }
    }
    public UInt16 v;
};

class servo_stat_word
{
    public servo_stat_word()
    {
        v = 0;
    }
```

```
public UInt16 ready_to_switch_on
{
    get { return Uint16BitGet(v, 0); }
    set { Uint16BitSet(ref v, 0, value); }
}
public UInt16 switched_on
{
    get { return Uint16BitGet(v, 1); }
    set { Uint16BitSet(ref v, 1, value); }
}
public UInt16 operation_enabled
{
    get { return Uint16BitGet(v, 2); }
    set { Uint16BitSet(ref v, 2, value); }
}
public UInt16 fault
{
    get { return Uint16BitGet(v, 3); }
    set { Uint16BitSet(ref v, 3, value); }
}
public UInt16 voltage_enabled
{
    get { return Uint16BitGet(v, 4); }
    set { Uint16BitSet(ref v, 4, value); }
}
public UInt16 quick_stop
{
    get { return Uint16BitGet(v, 5); }
    set { Uint16BitSet(ref v, 5, value); }
}
public UInt16 switch_on_disabled
{
    get { return Uint16BitGet(v, 6); }
    set { Uint16BitSet(ref v, 6, value); }
}
public UInt16 warning
{
    get { return Uint16BitGet(v, 7); }
    set { Uint16BitSet(ref v, 7, value); }
}
public UInt16 remote
{
    get { return Uint16BitGet(v, 9); }
```

```
        set { Uint16BitSet(ref v, 9, value); }
    }
    public UInt16 target_reached
    {
        get { return Uint16BitGet(v, 10); }
        set { Uint16BitSet(ref v, 10, value); }
    }
    public UInt16 internal_limit_active
    {
        get { return Uint16BitGet(v, 11); }
        set { Uint16BitSet(ref v, 11, value); }
    }
    public UInt16 v;
};

class pdo_entrys_config
{
    public class servo_entrys_config
    {
        public Int32 po_offset_mode;
        public Int32 po_offset_ctrl;
        public Int32 po_offset_pos;
        public Int32 pi_offset_mode;
        public Int32 pi_offset_stat;
        public Int32 pi_offset_pos;
        public Int32 pi_offset_err;
        public Int32 pi_offset_inputs;
    }
    public pdo_entrys_config()
    {
        servo_offset = new servo_entrys_config[NUM_SERVOS];
        for (int i = 0; i < NUM_SERVOS; i++) servo_offset[i] = new servo_entrys_config();
        pi_offset_di = new Int32[NUM_DI];
        po_offset_do = new Int32[NUM_DO];

    }
    [MarshalAs(UnmanagedType.ByValArray, SizeConst = (int)NUM_SERVOS)]
    public servo_entrys_config[] servo_offset;
    [MarshalAs(UnmanagedType.ByValArray, SizeConst = (int)NUM_DI)]
    public Int32[] pi_offset_di;
    [MarshalAs(UnmanagedType.ByValArray, SizeConst = (int)NUM_DO)]
    public Int32[] po_offset_do;
};
```

```
class servo_output
{
    public servo_output()
    {
        mode = (byte)OP_MODE.OP_MODE_CSP;
        ctrl = new servo_ctrl_word();
        p = 0;
    }

    public byte mode;
    public servo_ctrl_word ctrl;
    public Int32 p;
};

class servo_input
{
    public servo_input()
    {
        mode = (byte)OP_MODE.OP_MODE_CSP;
        stat = new servo_stat_word();
        p = 0;
        error = 0;
        inputs = 0;
    }

    public byte mode;
    public servo_stat_word stat;
    public Int32 p;
    public UInt16 error;
    public UInt32 inputs;
};

class proc_img_o
{
    public servo_output[] servos = new servo_output[NUM_SERVOS];
    public UInt16[] outputs = new UInt16[NUM_DO];

    public proc_img_o()
    {
        for (int i = 0; i < NUM_SERVOS; i++) servos[i] = new servo_output();
        for (int i = 0; i < NUM_DO; i++) outputs[i] = new UInt16();
    }
    public void CopyToOutputs(ref byte[] buff)
```

```
    {
        for (int i = 0; i < NUM_SERVOS; i++)
        {
            if (__entrys_config.servo_offset[i].po_offset_mode != -1)
buff[__entrys_config.servo_offset[i].po_offset_mode] = servos[i].mode;
            if (__entrys_config.servo_offset[i].po_offset_ctrl != -1)
CopyToByteArray(servos[i].ctrl.v, ref buff,
__entrys_config.servo_offset[i].po_offset_ctrl);
            if (__entrys_config.servo_offset[i].po_offset_pos != -1)
CopyToByteArray((UInt32)servos[i].p, ref buff,
__entrys_config.servo_offset[i].po_offset_pos);
        }
        for (int i = 0; i < NUM_DO; i++)
        {
            if (__entrys_config.po_offset_do[i] != -1)
CopyToByteArray((UInt16)outputs[i], ref buff, __entrys_config.po_offset_do[i]);
        }
    }

    public static void CopyToByteArray(UInt16 v, ref byte[] buff, int start)
    {
        buff[start + 0] = (byte)v;
        buff[start + 1] = (byte)(v >> 8);
    }
    public static void CopyToByteArray(UInt32 v, ref byte[] buff, int start)
    {
        buff[start + 0] = (byte)v;
        buff[start + 1] = (byte)(v >> 8);
        buff[start + 2] = (byte)(v >> 16);
        buff[start + 3] = (byte)(v >> 24);
    }
    public static void CopyToByteArray(UInt64 v, ref byte[] buff, int start)
    {
        buff[start + 0] = (byte)v;
        buff[start + 1] = (byte)(v >> 8);
        buff[start + 2] = (byte)(v >> 16);
        buff[start + 3] = (byte)(v >> 24);
        buff[start + 4] = (byte)(v >> 32);
        buff[start + 5] = (byte)(v >> 40);
        buff[start + 6] = (byte)(v >> 48);
        buff[start + 7] = (byte)(v >> 56);
    }
};
```

```
class proc_img_i
{
    public servo_input[] servos = new servo_input[NUM_SERVOS];
    public UInt16[] inputs = new UInt16[NUM_DI];

    public proc_img_i()
    {
        for (int i = 0; i < NUM_SERVOS; i++) servos[i] = new servo_input();
        for (int i = 0; i < NUM_DI; i++) inputs[i] = new UInt16();
    }

    public void CopyFromInputs(byte[] buff)
    {
        for (int i = 0; i < NUM_SERVOS; i++)
        {
            if (__entrys_config.servo_offset[i].pi_offset_mode != -1) servos[i].mode =
buff[__entrys_config.servo_offset[i].po_offset_mode];

           if (__entrys_config.servo_offset[i].pi_offset_stat != -1) servos[i].stat.v
= BitConverter.ToUInt16(buff, __entrys_config.servo_offset[i].pi_offset_stat);
            if (__entrys_config.servo_offset[i].pi_offset_pos != -1) servos[i].p =
BitConverter.ToInt32(buff, __entrys_config.servo_offset[i].pi_offset_pos);
            if (__entrys_config.servo_offset[i].pi_offset_err != -1) servos[i].error =
BitConverter.ToUInt16(buff, __entrys_config.servo_offset[i].pi_offset_err);
        }
        for (int i = 0; i < NUM_DO; i++)
        {
            if (__entrys_config.po_offset_do[i] != -1) inputs[i] =
BitConverter.ToUInt16(buff, __entrys_config.pi_offset_di[i]);
        }
    }
};
```

其中 pdo_entrys_config 用来存储变量的偏移，而 proc_img_o 和 proc_img_i 除了定义 PDO 数据结构外，还定义了 CopyToOutputs 和 CopyFromInput 函数，用来将读取到的连续 PDO 数据域转换为 C#变量。

2.6 主站控制

本节介绍如何调用 PCIe 主站卡的 SDK 接口来控制 EtherCAT 总线。本示例采用主站的同步队列接口交换数据。同步队列的通信原理如图。

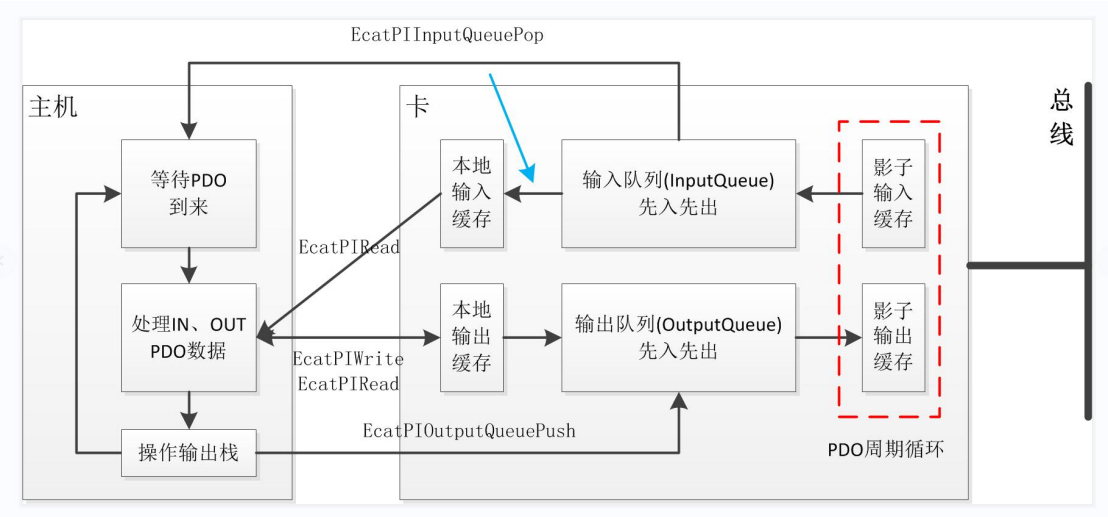

图 2.9　同步队列通信原理

2.6.1 初始化主站

首先启动 EtherCAT，其中 ALIAS 需要填入主站卡的别名编码器值，“protal3.xml”需要替换为用户通过 AWStudio 导出到 ENI.xml 文件。

```
//PCIe-2E 只有一个通道,PCIe-4E 有两个通道
EXIT_IF_FAIL("EcatOpen", EcatOpen(ref ecat_dev, BOARD_ALIAS(alias), channel));
RETURN_IF_FAIL("EcatBusRun", EcatBusRun(ecat_dev, eni_file));
```

2.6.2 EtherCAT 状态切换

请求 EtherCAT 总线切换状态。

```
// 请求切换状态
byte state = 0;
RETURN_IF_FAIL("EcatRequestMasterState", EcatRequestMasterState(ecat_dev,
EcatState0));
for (int i = 0; ; i++)
{
    RETURN_IF_FAIL("EcatGetMasterState", EcatGetMasterState(ecat_dev, ref state),
false);
    Console.WriteLine("{1,2}: request is: 8, curr is: {0}", state, i);
    Thread.Sleep(500);
    if (state == EcatState0) break;
}
```

2.6.3 初始化 PI 镜像相关变量

首先，通过 EcatGetEniInfo 接口获取 PDO 变量的长度等信息。然后创建 inputs 和 outputs 缓冲区，并创建 proc_img_i 和 proc_img_o 变量。最后需要初始化存储 PDO 偏移的变量 pdo_entrys_config_init。

```
// 过程镜像输入输出循环
ECAT_ENI_INFO ptInfo = new ECAT_ENI_INFO();
```

```
RETURN_IF_FAIL("EcatGetEniInfo", EcatGetEniInfo(ecat_dev, ref ptInfo));
Console.WriteLine("Eni Info input size:{0}, output size: {1}",
ptInfo.u32PIInputByteSize, ptInfo.u32PIOutputByteSize);

pdo_entrys_config_init();

byte[] inputs = new Byte[ptInfo.u32PIInputByteSize];
byte[] outputs = new Byte[ptInfo.u32PIOutputByteSize];
proc_img_o po = new proc_img_o();
proc_img_i pi = new proc_img_i();
```

2.6.4 使能 PI 总线数据交换

在控制电机和初始化电机状态之前，需要先使能 PI 镜像交换

```
RETURN_IF_FAIL("EcatPIEnable", EcatPIEnable(ecat_dev));
```

2.6.5 预填充 PDO 队列

为了减少用户逻辑和系统抖动对 EtherCAT 总线造成的影响，可以向 PDO 队列里预填充几帧数据作为缓冲。

```
for (int i = 0; i < 2; i++)
{
    EcatPIOutputQueuePush(ecat_dev, false, 100);
}
```

2.6.6 EtherCAT 周期处理主循环

主循环中，EcatPIInputQueuePop 等待队列接收可用数据。用户逻辑更新数据后，通过 EcatPIOutputQueuePush 函数将数据填入队列中。

```
while (true)
{
    if (EcatPIInputQueuePop(ecat_dev, false, 100) == 0)
    {
        loops++;

        // 显示设置状态
        if (loops % 1000 == 0)
        {
            RETURN_IF_FAIL("EcatPIInputQueueSize", EcatPIOutputQueueSize(ecat_dev,
ref ecat_queue_size), false);
            Console.WriteLine("EcatPIInputQueue size: {0}", ecat_queue_size);
        }

        RETURN_IF_FAIL("EcatPIRead", EcatPIRead(ecat_dev, PI_AREA_LOCAL_INPUT, 0,
ptInfo.u32PIInputByteSize, ref inputs[0]), false);
```

```
        // 获取输入数据
        pi.CopyFromInputs(inputs);
        for (int i = 0; i < NUM_SERVOS; i++) __servos[i].input = pi.servos[i];
        __user_controller.UpdateButton(pi.inputs);

        // 启动电机
        __user_controller.run(ref run_cmd, ref stop_cmd, ref halt_cmd);
        if (run_cmd != 0)
        {
            for (int i = 0; i < NUM_SERVOS; i++) __servos[i].motor_run(i, loops,
__range_min[i], __range_max[i], __step_size[i]);
        }

        // 生成输出数据
        for (int i = 0; i < NUM_SERVOS; i++) po.servos[i] = __servos[i].output;
        __user_controller.UpdateLED(ref po.outputs);
        po.CopyToOutputs(ref outputs);

        RETURN_IF_FAIL("EcatPIRead", EcatPIWrite(ecat_dev, PI_AREA_LOCAL_OUTPUT, 0,
ptInfo.u32PIOutputByteSize, ref outputs[0]), false);
        RETURN_IF_FAIL("EcatPIOutputQueuePush", EcatPIOutputQueuePush(ecat_dev, false,
100), false);
    }
}
```

2.6.7 退出

当应用程序需要退出时，需要销毁 ECAT 主站。

```
    // 退出
    EXIT_IF_FAIL("EcatBusStop", EcatBusStop(ecat_dev));
    EXIT_IF_FAIL("EcatClose", EcatClose(ecat_dev));
```

2.7 按键及指示灯控制

该应用中包括运行键（绿）、停止键（红）、运行状态灯（绿）、紧急状态灯（红）、接近传感器等外设，这些外设功能如下。

1. 运行状态灯用于指示电机运行，停止状态下为绿灯闪烁，运行状态下为绿灯常亮，紧急状态下绿灯熄灭。

2. 紧急状态灯用于指示系统进入紧急状态。正常状态下红灯熄灭。紧急状态下红灯常亮，绿灯熄灭。

3. 运行键用于启动电机，进入运行状态。停止键用于停止电机运行，进入停止状态。

4. 接近传感器检测到金属物体接近时，会输出低电平。此时系统需要进入紧急状态。进入紧急状态后，必须用运行键重启电机系统。

```
private class user_control
{
    const ushort LED_GREEN = 0;   // 绿灯
    const ushort LED_RED = 1;     // 红灯

    const ushort BTN_CLOSE = 0;   // 接近传感器
    const ushort BTN_RUN = 1;     // 绿色按钮
    const ushort BTN_STOP = 2;    // 红色按钮

    ushort led_green = 0;
    ushort led_red = 0;
    ushort btn_close = 0;
    ushort btn_run = 0;
    ushort btn_stop = 0;
    static int count = 0;

    public void UpdateButton(UInt16[] buff)
    {
        if (__entrys_config.pi_offset_di[0] != -1)
        {
            btn_close = Uint16BitGet((UInt16)buff[0], BTN_CLOSE);
            btn_run = Uint16BitGet((UInt16)buff[0], BTN_RUN);
            btn_stop = Uint16BitGet((UInt16)buff[0], BTN_STOP);
        }
    }

    public void UpdateLED(ref UInt16[] buff)
    {
        if (__entrys_config.po_offset_do[0] != -1)
        {
            ushort temp = (UInt16)buff[0];
            Uint16BitSet(ref temp, LED_GREEN, led_green);
            Uint16BitSet(ref temp, LED_RED, led_red);
            buff[0] = temp;
        }
    }
    public void run(ref int run_cmd, ref int stop_cmd, ref int halt_cmd)
    {
        if (btn_run == 0)
        {
            // 输入低有效
            run_cmd = 1;
```

```
            stop_cmd = 0;
            halt_cmd = 0;
        }
        if(btn_stop == 0)
        {
            // 输入低有效
            run_cmd = 0;
            stop_cmd = 1;
        }
        if (btn_close == 0)
        {
            // 输入低有效
            run_cmd = 0;
            halt_cmd = 1;
        }
        if(run_cmd == 0)
        {
            count++;
            if (count > 500)
            {
                if (led_green == 0) led_green = 1;
                else led_green = 0;
                count = 0;
            }
        }
        else
        {
            led_green = 1;
        }
        if (halt_cmd == 0)
        {
            led_red = 0;
        }
        else
        {
            led_green = 0;
            led_red = 1;
        }
    }
}
```

2.8 电机控制

2.8.1 CiA402 状态机简介

以下为 CiA402 规范定义的状态机转换模型。

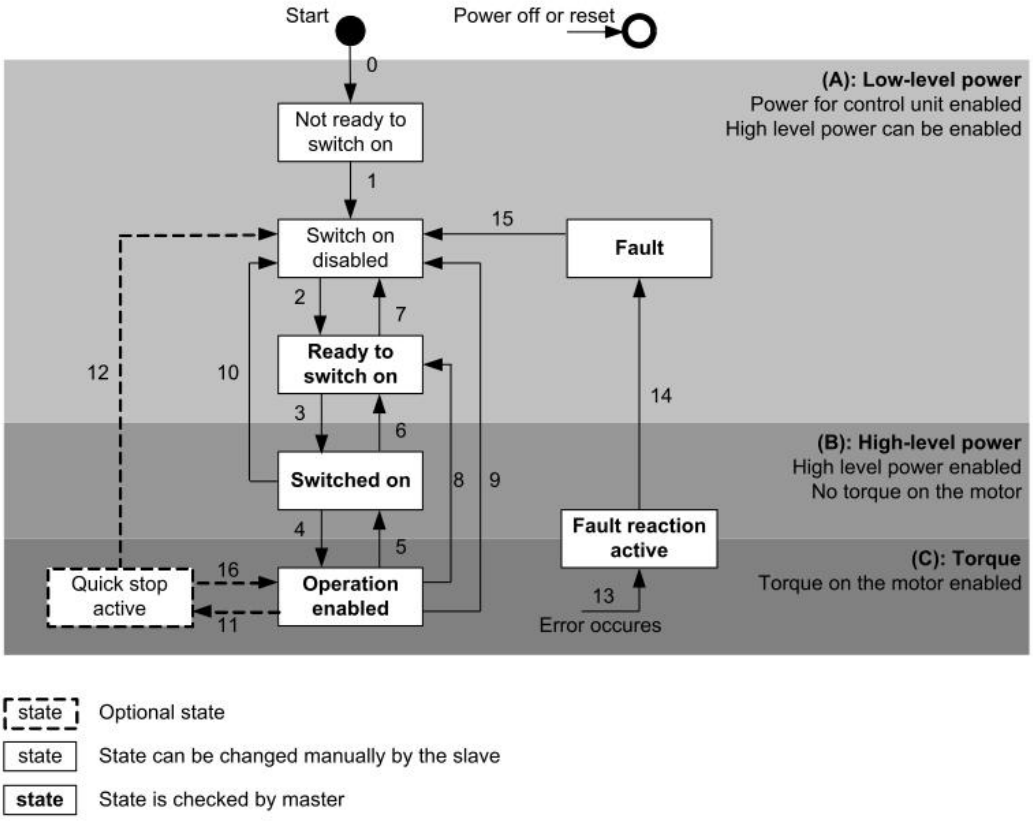

图 2.10 CiA402 状态机

CiA402 控制字用于发送状态转换请求，其位定义如下。

The bits of the *controlword* are defined as follows:

15	11	10	9	8	7	6	4	3	2	1	0
manufacturer specific		reserved		halt	Fault reset	Operation mode specific		Enable operation	Quick stop	Enable voltage	Switch on
O		O		O	M	O		M	M	M	M

MSB LSB

0 - Optional M - Mandatory

BITS 0 – 3 AND 7:

Device control commands are triggered by the following bit patterns in the *controlword*:

Command	Bit of the *controlword*					Transitions
	Fault reset	Enable operation	Quick stop	Enable voltage	Switch on	
Shutdown	0	X	1	1	0	2,6,8
Switch on	0	0	1	1	1	3*
Switch on	0	1	1	1	1	3**
Disable voltage	0	X	X	0	X	7,9,10,12
Quick stop	0	X	0	1	X	7,10,11
Disable operation	0	0	1	1	1	5
Enable operation	0	1	1	1	1	4,16
Fault reset	↑	X	X	X	X	15

Table 4: Device control commands **(bits marked X are irrelevant, * ... In the state SWITCHED ON the drive executes the functionality of this state., ** ... It exists no functionality in the state SWITCHED ON. The drive does not do any in this state.)**

图 2.11 CiA402 标准控制字定义

发送状态请求后，通过状态字来确认状态转换是否成功，成功后才能继续转换状态，状态字的位定义如下。

Bit	Description	M /O
0	Ready to switch on	M
1	Switched on	M
2	Operation enabled	M
3	Fault	M
4	Voltage enabled	M
5	Quick stop	M
6	Switch on disabled	M
7	Warning	O
8	Manufacturer specific	O
9	Remote	M
10	Target reached	M
11	Internal limit active	M
12 - 13	Operation mode specific	O
14 - 15	Manufacturer specific	O

Table 6: Bits in the *statusword*

图 2.12 CiA402 标准状态字定义

BITS 0 – 3, 5 AND 6:

The following bits indicate the status of the device:

Value (binary)	State
xxxx xxxx x0xx 0000	Not ready to switch on
xxxx xxxx x1xx 0000	Switch on disabled
xxxx xxxx x01x 0001	Ready to switch on
xxxx xxxx x01x 0011	Switched on
xxxx xxxx x01x 0111	Operation enabled
xxxx xxxx x00x 0111	Quick stop active
xxxx xxxx x0xx 1111	Fault reaction active
xxxx xxxx x0xx 1000	Fault

Table 7: Device state bits (x ... irrelevant for this state)

图 2.13 状态字判断

2.8.2 CiA402 运行模式&电机数量

```
        enum OP_MODE
        {
            OP_MODE_PP = 1,
            OP_MODE_PV = 3,
            OP_MODE_PT = 4,
            OP_MODE_HM = 6,
            OP_MODE_CSP = 8,
            OP_MODE_CSV = 9,
            OP_MODE_CST = 10,
        };

        const uint NUM_SERVOS = 1;
        const uint NUM_DO = 1;
        const uint NUM_DI = 1;

byte run_mode = (byte)OP_MODE.OP_MODE_CSP;
```

设置电机运行模式，本示例为 CSP 模式。

2.8.3 SDO 命令设置 CiA402 电机运行模式

motor_mode_init 初始化运行模式，主要是通过 SDO 命令写邮箱 0x6060 对象，设置运行模式。

```
// 配置电机运行模式
RETURN_IF_FAIL("EcatCoeSDODownload", EcatCoeSDODownload(ecat_dev, 3, 0x6060, 0, 1, ref run_mode, 1000));
```

2.8.4 CiA402 状态转换处理

CiA402 协议需要维护状态机的切换，在 motor_control 函数中实现，包括电机启动和错误响应及处理。

CiA402 状态机的转换，需要在 PDO 周期中运行。电机的启动、急停、错误检测和清除等，都依赖 CiA402 状态机实现。意味着 motor_control 需要在主循环中反复调用。

```
public bool motor_control(int axis)
{
    output.ctrl.v = 0;
    output.ctrl.enable_voltage = 1;
    output.ctrl.quick_stop = 1;
    output.ctrl.enable_operation = (UInt16)(input.stat.switched_on | input.stat.operation_enabled);
    output.ctrl.switch_on = input.stat.ready_to_switch_on;

    if (input.stat.fault != 0 && fault_reset_delay == 0)
```

```
    {
        // 延时 1 秒再尝试错误恢复，防止伺服在错误和恢复中反复快速切换损坏电路
        Console.WriteLine("axis {0}: delay fault reset, ctrl:{1:X}, stat:{2:X}", axis,
output.ctrl.v, input.stat.v);
        fault_reset_delay = 2000; // 2s(即 2000 个周期)
        run_delay = 2000; // 当错误恢复成功伺服出力后，延时 2s 再开始加速(根据抱闸动作时间
适当调整)
        return input.stat.operation_enabled != 0;
    }

    // 伺服发生错误，且在延时等待处理中
    if (fault_reset_delay != 0)
    {
        fault_reset_delay--;
        if (fault_reset_delay == 0)
        {
            // 延时减到 0，尝试进行错误恢复
            Console.WriteLine("axis {0}: start fault reset", axis);
            output.ctrl.fault_reset = 1;
        }
    }

    return input.stat.operation_enabled != 0;
}
```

2.8.5 EtherCAT 周期数据处理控制电机转动

控制电机往复运动的主要逻辑在 main 函数中循环实现。在 CSP 模式下，程序通过计算得到电机位置后，写到 PDO 变量中。然后主站卡在下一次周期将更新后的电机位置发送给从站，从站就能控制电机转动。

```
public void motor_run(int axis, UInt64 loops, Int32 range_min, Int32 range_max, double
step)
{
    bool run = motor_control(axis);

    // 显示设置状态
    if (loops % 1000 == 0)
    {
        Console.WriteLine("servo[{0}]: run:{4}, p={1,10}, ctrl:0x{2:X4} stat=0x{3:X4}",
axis, input.p, output.ctrl.v, input.stat.v, run);
    }
    // 伺服未出力，或已出力但延时未结束，应停止转动
    if (!run || run_delay != 0)
```

```
    {
        output.p = input.p;
        zero_p = (double)output.p;
        offset_p = 0;
        reverse = false;
    }

    // 伺服已出力，延时计数递减
    if (run && run_delay != 0) run_delay--;

    // 伺服已出力，延时结束，进行正常控制
    if (run && run_delay == 0)
    {
        // 不同轴单位可能不一样，下表定义各轴位置范围及增量
        if (offset_p < range_min) reverse = false;
        if (offset_p > range_max) reverse = true;
        offset_p += (reverse ? -1 : 1) * step;
        output.p = (Int32)(zero_p + offset_p);
    }
}
```

2.9 完整示例代码

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Threading;
using System.Threading.Tasks;
using System.Runtime.InteropServices;

using static pci.zecm;

namespace test
{
    class Program
    {
        public enum OP_MODE
        {
            OP_MODE_PP = 1,
            OP_MODE_PV = 3,
            OP_MODE_PT = 4,
            OP_MODE_HM = 6,
            OP_MODE_CSP = 8,
```

```
            OP_MODE_CSV = 9,
            OP_MODE_CST = 10,
        };

        const uint NUM_SERVOS = 1;
        const uint NUM_DO = 1;
        const uint NUM_DI = 1;

        static void EXIT_IF_FAIL(string expr, int ret)
        {
            if (ret != 0)
            {
                Console.WriteLine("{0} failed, error({1}): {2}", expr, ret,
DriverGetErrStr(ret));
                Environment.Exit(1);
            }
        }
        static void RETURN_IF_FAIL(string expr, int ret, bool show_success = true)
        {
            if (ret != 0)
            {
                throw new Exception(string.Format("{0} failed, error({1}): {2}", expr,
ret, DriverGetErrStr(ret)));
            }
            if (show_success) Console.WriteLine("{0} succeeded.", expr);
        }

        static UInt16 Uint16BitGet(UInt16 v, UInt16 bit) { return (UInt16)((v >> bit)
& 0x1); }
        static void Uint16BitSet(ref UInt16 v, UInt16 bit, UInt16 value) { v = (UInt16)((v
& ~(1 << bit)) | ((value & 1) << bit)); }

        class servo_ctrl_word
        {
            public servo_ctrl_word()
            {
                v = 0;
            }
            public UInt16 switch_on
            {
                get { return Uint16BitGet(v, 0); }
                set { Uint16BitSet(ref v, 0, value); }
            }
```

```
        public UInt16 enable_voltage
        {
            get { return Uint16BitGet(v, 1); }
            set { Uint16BitSet(ref v, 1, value); }
        }
        public UInt16 quick_stop
        {
            get { return Uint16BitGet(v, 2); }
            set { Uint16BitSet(ref v, 2, value); }
        }
        public UInt16 enable_operation
        {
            get { return Uint16BitGet(v, 3); }
            set { Uint16BitSet(ref v, 3, value); }
        }
        public UInt16 fault_reset
        {
            get { return Uint16BitGet(v, 7); }
            set { Uint16BitSet(ref v, 7, value); }
        }
        public UInt16 v;
    };
    class servo_stat_word
    {
        public servo_stat_word()
        {
            v = 0;
        }
        public UInt16 ready_to_switch_on
        {
            get { return Uint16BitGet(v, 0); }
            set { Uint16BitSet(ref v, 0, value); }
        }
        public UInt16 switched_on
        {
            get { return Uint16BitGet(v, 1); }
            set { Uint16BitSet(ref v, 1, value); }
        }
        public UInt16 operation_enabled
        {
            get { return Uint16BitGet(v, 2); }
            set { Uint16BitSet(ref v, 2, value); }
        }
```

```
        public UInt16 fault
        {
            get { return Uint16BitGet(v, 3); }
            set { Uint16BitSet(ref v, 3, value); }
        }
        public UInt16 voltage_enabled
        {
            get { return Uint16BitGet(v, 4); }
            set { Uint16BitSet(ref v, 4, value); }
        }
        public UInt16 quick_stop
        {
            get { return Uint16BitGet(v, 5); }
            set { Uint16BitSet(ref v, 5, value); }
        }
        public UInt16 switch_on_disabled
        {
            get { return Uint16BitGet(v, 6); }
            set { Uint16BitSet(ref v, 6, value); }
        }
        public UInt16 warning
        {
            get { return Uint16BitGet(v, 7); }
            set { Uint16BitSet(ref v, 7, value); }
        }
        public UInt16 remote
        {
            get { return Uint16BitGet(v, 9); }
            set { Uint16BitSet(ref v, 9, value); }
        }
        public UInt16 target_reached
        {
            get { return Uint16BitGet(v, 10); }
            set { Uint16BitSet(ref v, 10, value); }
        }
        public UInt16 internal_limit_active
        {
            get { return Uint16BitGet(v, 11); }
            set { Uint16BitSet(ref v, 11, value); }
        }
        public UInt16 v;
    };
```

```
        class pdo_entrys_config
        {
            public class servo_entrys_config
            {
                public Int32 po_offset_mode;
                public Int32 po_offset_ctrl;
                public Int32 po_offset_pos;
                public Int32 pi_offset_mode;
                public Int32 pi_offset_stat;
                public Int32 pi_offset_pos;
                public Int32 pi_offset_err;
                public Int32 pi_offset_inputs;
            }
            public pdo_entrys_config()
            {
                servo_offset = new servo_entrys_config[NUM_SERVOS];
                for (int i = 0; i < NUM_SERVOS; i++) servo_offset[i] = new
servo_entrys_config();
                pi_offset_di = new Int32[NUM_DI];
                po_offset_do = new Int32[NUM_DO];

            }
            [MarshalAs(UnmanagedType.ByValArray, SizeConst = (int)NUM_SERVOS)]
            public servo_entrys_config[] servo_offset;
            [MarshalAs(UnmanagedType.ByValArray, SizeConst = (int)NUM_DI)]
            public Int32[] pi_offset_di;
            [MarshalAs(UnmanagedType.ByValArray, SizeConst = (int)NUM_DO)]
            public Int32[] po_offset_do;
        };

        class servo_output
        {
            public servo_output()
            {
                mode = (byte)OP_MODE.OP_MODE_CSP;
                ctrl = new servo_ctrl_word();
                p = 0;
            }

            public byte mode;
            public servo_ctrl_word ctrl;
            public Int32 p;
        };
```

```
        class servo_input
        {
            public servo_input()
            {
                mode = (byte)OP_MODE.OP_MODE_CSP;
                stat = new servo_stat_word();
                p = 0;
                error = 0;
                inputs = 0;
            }

            public byte mode;
            public servo_stat_word stat;
            public Int32 p;
            public UInt16 error;
            public UInt32 inputs;
        };

        class proc_img_o
        {
            public servo_output[] servos = new servo_output[NUM_SERVOS];
            public UInt16[] outputs = new UInt16[NUM_DO];

            public proc_img_o()
            {
                for (int i = 0; i < NUM_SERVOS; i++) servos[i] = new servo_output();
                for (int i = 0; i < NUM_DO; i++) outputs[i] = new UInt16();
            }
            public void CopyToOutputs(ref byte[] buff)
            {
                for (int i = 0; i < NUM_SERVOS; i++)
                {
                    if (__entrys_config.servo_offset[i].po_offset_mode != -1)
buff[__entrys_config.servo_offset[i].po_offset_mode] = servos[i].mode;
                    if (__entrys_config.servo_offset[i].po_offset_ctrl != -1)
CopyToByteArray(servos[i].ctrl.v, ref buff,
__entrys_config.servo_offset[i].po_offset_ctrl);
                    if (__entrys_config.servo_offset[i].po_offset_pos != -1)
CopyToByteArray((UInt32)servos[i].p, ref buff,
__entrys_config.servo_offset[i].po_offset_pos);
                }
                for (int i = 0; i < NUM_DO; i++)
```

```
                {
                    if (__entrys_config.po_offset_do[i] != -1)
CopyToByteArray((UInt16)outputs[i], ref buff, __entrys_config.po_offset_do[i]);
                }
            }

            public static void CopyToByteArray(UInt16 v, ref byte[] buff, int start)
            {
                buff[start + 0] = (byte)v;
                buff[start + 1] = (byte)(v >> 8);
            }
            public static void CopyToByteArray(UInt32 v, ref byte[] buff, int start)
            {
                buff[start + 0] = (byte)v;
                buff[start + 1] = (byte)(v >> 8);
                buff[start + 2] = (byte)(v >> 16);
                buff[start + 3] = (byte)(v >> 24);
            }
            public static void CopyToByteArray(UInt64 v, ref byte[] buff, int start)
            {
                buff[start + 0] = (byte)v;
                buff[start + 1] = (byte)(v >> 8);
                buff[start + 2] = (byte)(v >> 16);
                buff[start + 3] = (byte)(v >> 24);
                buff[start + 4] = (byte)(v >> 32);
                buff[start + 5] = (byte)(v >> 40);
                buff[start + 6] = (byte)(v >> 48);
                buff[start + 7] = (byte)(v >> 56);
            }
        };

        class proc_img_i
        {
            public servo_input[] servos = new servo_input[NUM_SERVOS];
            public UInt16[] inputs = new UInt16[NUM_DI];

            public proc_img_i()
            {
                for (int i = 0; i < NUM_SERVOS; i++) servos[i] = new servo_input();
                for (int i = 0; i < NUM_DI; i++) inputs[i] = new UInt16();
            }
```

```
            public void CopyFromInputs(byte[] buff)
            {
                for (int i = 0; i < NUM_SERVOS; i++)
                {
                    if (__entrys_config.servo_offset[i].pi_offset_mode != -1)
servos[i].mode = buff[__entrys_config.servo_offset[i].po_offset_mode];
                    if (__entrys_config.servo_offset[i].pi_offset_stat != -1)
servos[i].stat.v = BitConverter.ToUInt16(buff,
__entrys_config.servo_offset[i].pi_offset_stat);
                    if (__entrys_config.servo_offset[i].pi_offset_pos != -1)
servos[i].p = BitConverter.ToInt32(buff,
__entrys_config.servo_offset[i].pi_offset_pos);
                    if (__entrys_config.servo_offset[i].pi_offset_err != -1)
servos[i].error = BitConverter.ToUInt16(buff,
__entrys_config.servo_offset[i].pi_offset_err);
                }
                for (int i = 0; i < NUM_DO; i++)
                {
                    if (__entrys_config.po_offset_do[i] != -1) inputs[i] =
BitConverter.ToUInt16(buff, __entrys_config.pi_offset_di[i]);
                }
            }
        };

        class servos_t
        {
            public servo_output output = new servo_output();         // 电机输出
            public servo_input input = new servo_input();            // 电机输入

            public bool motor_control(int axis)
            {
                output.ctrl.v = 0;
                output.ctrl.enable_voltage = 1;
                output.ctrl.quick_stop = 1;
                output.ctrl.enable_operation = (UInt16)(input.stat.switched_on |
input.stat.operation_enabled);
                output.ctrl.switch_on = input.stat.ready_to_switch_on;

                if (input.stat.fault != 0 && fault_reset_delay == 0)
                {
                    // 延时 1 秒再尝试错误恢复，防止伺服在错误和恢复中反复快速切换损坏电路
                    Console.WriteLine("axis {0}: delay fault reset, ctrl:{1:X},
stat:{2:X}", axis, output.ctrl.v, input.stat.v);
```

```
                    fault_reset_delay = 2000; // 2s(即 2000 个周期)
                    run_delay = 2000; // 当错误恢复成功伺服出力后，延时 2s 再开始加速(根据抱闸动作时间适当调整)
                    return input.stat.operation_enabled != 0;
                }

                // 伺服发生错误，且在延时等待处理中
                if (fault_reset_delay != 0)
                {
                    fault_reset_delay--;
                    if (fault_reset_delay == 0)
                    {
                        // 延时减到 0，尝试进行错误恢复
                        Console.WriteLine("axis {0}: start fault reset", axis);
                        output.ctrl.fault_reset = 1;
                    }
                }

                return input.stat.operation_enabled != 0;
            }
            public void motor_run(int axis, UInt64 loops, Int32 range_min, Int32 range_max, double step)
            {
                bool run = motor_control(axis);

                // 显示设置状态
                if (loops % 1000 == 0)
                {
                    Console.WriteLine("servo[{0}]: run:{4}, p={1,10}, ctrl:0x{2:X4} stat=0x{3:X4}", axis, input.p, output.ctrl.v, input.stat.v, run);
                }
                // 伺服未出力，或已出力但延时未结束，应停止转动
                if (!run || run_delay != 0)
                {
                    output.p = input.p;
                    zero_p = (double)output.p;
                    offset_p = 0;
                    reverse = false;
                }

                // 伺服已出力，延时计数递减
                if (run && run_delay != 0) run_delay--;
```

```
            // 伺服已出力，延时结束，进行正常控制
            if (run && run_delay == 0)
            {
                // 不同轴单位可能不一样，下表定义各轴位置范围及增量
                if (offset_p < range_min) reverse = false;
                if (offset_p > range_max) reverse = true;
                offset_p += (reverse ? -1 : 1) * step;
                output.p = (Int32)(zero_p + offset_p);
            }
        }

        private int run_delay = 0;                              // 延时启动
        private int fault_reset_delay = 0;                      // 延时再错误恢复
        private double zero_p = 0;                              // 零点位置
        private double offset_p = 0;                            // 偏移输出位置
        private bool reverse = false;                           // 当前方向
    };

    static servos_t[] __servos = new servos_t[]
    {
        new servos_t(),
        new servos_t(),
        new servos_t(),
    };

    private class user_control
    {
        const ushort LED_GREEN = 0;   // 绿灯
        const ushort LED_RED = 1;     // 红灯

        const ushort BTN_CLOSE = 0;   // 接近传感器
        const ushort BTN_RUN = 1;     // 绿色按钮
        const ushort BTN_STOP = 2;    // 红色按钮

        ushort led_green = 0;
        ushort led_red = 0;
        ushort btn_close = 0;
        ushort btn_run = 0;
        ushort btn_stop = 0;

        static int count = 0;

        public void UpdateButton(UInt16[] buff)
```

```
        {
            if (__entrys_config.pi_offset_di[0] != -1)
            {
                btn_close = Uint16BitGet((UInt16)buff[0], BTN_CLOSE);
                btn_run = Uint16BitGet((UInt16)buff[0], BTN_RUN);
                btn_stop = Uint16BitGet((UInt16)buff[0], BTN_STOP);
            }
        }

        public void UpdateLED(ref UInt16[] buff)
        {
            if (__entrys_config.po_offset_do[0] != -1)
            {
                ushort temp = (UInt16)buff[0];
                Uint16BitSet(ref temp, LED_GREEN, led_green);
                Uint16BitSet(ref temp, LED_RED, led_red);
                buff[0] = temp;
            }
        }

        public void run(ref int run_cmd, ref int stop_cmd, ref int halt_cmd)
        {
            if (btn_run == 0)
            {
                // 输入低有效
                run_cmd = 1;
                stop_cmd = 0;
                halt_cmd = 0;
            }
            if(btn_stop == 0)
            {
                // 输入低有效
                run_cmd = 0;
                stop_cmd = 1;
            }
            if (btn_close == 0)
            {
                // 输入低有效
                run_cmd = 0;
                halt_cmd = 1;
            }
```

```
                if(run_cmd == 0)
                {
                    count++;
                    if (count > 500)
                    {
                        if (led_green == 0) led_green = 1;
                        else led_green = 0;
                        count = 0;
                    }
                }
                else
                {
                    led_green = 1;
                }
                if (halt_cmd == 0)
                {
                    led_red = 0;
                }
                else
                {
                    led_green = 0;
                    led_red = 1;
                }
            }
        }

        static user_control __user_controller = new user_control();

        static pdo_entrys_config __entrys_config;

        static private void pdo_entrys_config_init()
        {
            __entrys_config = new pdo_entrys_config();
            int servo_pi_offset = 12, servo_po_offset = 12;
            for(int i = 0; i < NUM_SERVOS; i++)
            {
                __entrys_config.servo_offset[i].po_offset_mode = -1;
                __entrys_config.servo_offset[i].po_offset_ctrl = 0 + i *
servo_po_offset;
                __entrys_config.servo_offset[i].po_offset_pos = 2 + i *
servo_po_offset;
                __entrys_config.servo_offset[i].pi_offset_mode = -1;
```

```
                __entrys_config.servo_offset[i].pi_offset_stat = 0 + i *
servo_pi_offset;
                __entrys_config.servo_offset[i].pi_offset_pos = 2 + i *
servo_pi_offset;
                __entrys_config.servo_offset[i].pi_offset_err = 6 + i *
servo_pi_offset;
                __entrys_config.servo_offset[i].pi_offset_inputs = 8 + i *
servo_pi_offset;
            }
            for(int i = 0; i < NUM_DI; i++)
            {
                __entrys_config.pi_offset_di[i] = i * 16 + (int)NUM_SERVOS *
servo_pi_offset;
            }
            for (int i = 0; i < NUM_DO; i++)
            {
                __entrys_config.po_offset_do[i] = i * 16 + (int)NUM_SERVOS *
servo_po_offset;
            }
        }

        static Int32[] __range_min = new Int32[] { -50000 };
        static Int32[] __range_max = new Int32[] {  50000 };
        static double[] __step_size = new double[] { 50 };

        static void ServosTest(IntPtr ecat_dev, string eni_file)
        {
            RETURN_IF_FAIL("EcatBusRun", EcatBusRun(ecat_dev, eni_file));

            // 请求切换状态
            byte state = 0;
            RETURN_IF_FAIL("EcatRequestMasterState", EcatRequestMasterState(ecat_dev,
EcatStateO));
            for (int i = 0; ; i++)
            {
                RETURN_IF_FAIL("EcatGetMasterState", EcatGetMasterState(ecat_dev, ref
state), false);
                Console.WriteLine("{1,2}: request is: 8, curr is: {0}", state, i);
                Thread.Sleep(500);
                if (state == EcatStateO) break;
            }
```

```
            byte run_mode = (byte)OP_MODE.OP_MODE_CSP;

            // 配置电机运行模式
            RETURN_IF_FAIL("EcatCoeSDODownload", EcatCoeSDODownload(ecat_dev, 3,
0x6060, 0, 1, ref run_mode, 1000));

            // 预计填入数据
            for (int i = 0; i < 10; i++)
            {
                EcatPIOutputQueuePush(ecat_dev, false, 100);
            }

            // 过程镜像输入输出循环
            ECAT_ENI_INFO ptInfo = new ECAT_ENI_INFO();
            RETURN_IF_FAIL("EcatGetEniInfo", EcatGetEniInfo(ecat_dev, ref ptInfo));
            Console.WriteLine("Eni Info input size:{0}, output size: {1}",
ptInfo.u32PIInputByteSize, ptInfo.u32PIOutputByteSize);

            pdo_entrys_config_init();

            byte[] inputs = new Byte[ptInfo.u32PIInputByteSize];
            byte[] outputs = new Byte[ptInfo.u32PIOutputByteSize];
            proc_img_o po = new proc_img_o();
            proc_img_i pi = new proc_img_i();

            UInt64 loops = 0;
            UInt32 ecat_queue_size = 0;
            int run_cmd = 0, stop_cmd = 0, halt_cmd = 0;
            RETURN_IF_FAIL("EcatPIEnable", EcatPIEnable(ecat_dev));

            while (true)
            {
                if (EcatPIInputQueuePop(ecat_dev, false, 100) == 0)
                {
                    loops++;
                    // 显示设置状态
                    if (loops % 1000 == 0)
                    {
                        RETURN_IF_FAIL("EcatPIInputQueueSize",
EcatPIOutputQueueSize(ecat_dev, ref ecat_queue_size), false);
                        Console.WriteLine("EcatPIInputQueue size: {0}",
ecat_queue_size);
                    }
```

```
                    RETURN_IF_FAIL("EcatPIRead", EcatPIRead(ecat_dev,
PI_AREA_LOCAL_INPUT, 0, ptInfo.u32PIInputByteSize, ref inputs[0]), false);

                    // 获取输入数据
                    pi.CopyFromInputs(inputs);
                    for (int i = 0; i < NUM_SERVOS; i++) __servos[i].input = pi.servos[i];
                    __user_controller.UpdateButton(pi.inputs);

                    // 启动电机
                    __user_controller.run(ref run_cmd, ref stop_cmd, ref halt_cmd);
                    if (run_cmd != 0)
                    {
                        for (int i = 0; i < NUM_SERVOS; i++) __servos[i].motor_run(i,
loops, __range_min[i], __range_max[i], __step_size[i]);
                    }

                    // 生成输出数据
                    for (int i = 0; i < NUM_SERVOS; i++) po.servos[i] =
__servos[i].output;
                    __user_controller.UpdateLED(ref po.outputs);
                    po.CopyToOutputs(ref outputs);

                    RETURN_IF_FAIL("EcatPIRead", EcatPIWrite(ecat_dev,
PI_AREA_LOCAL_OUTPUT, 0, ptInfo.u32PIOutputByteSize, ref outputs[0]), false);
                    RETURN_IF_FAIL("EcatPIOutputQueuePush",
EcatPIOutputQueuePush(ecat_dev, false, 100), false);
                }
            }
        }

        static void Main(string[] args)
        {
            IntPtr ecat_dev = new IntPtr();
            UInt32 channel = 0, alias = 0;
            string eni_file;

            if (args.Length != 3)
            {
                Console.WriteLine("usage: sync_control_test alias channel eni_file");
                Environment.Exit(1);
            }

            alias = Convert.ToUInt32(args[0]);
```

```
            channel = Convert.ToUInt32(args[1]);
            eni_file = args[2];

            //PCIe-2E 只有一个通道,PCIe-4E 有两个通道
            EXIT_IF_FAIL("EcatOpen", EcatOpen(ref ecat_dev, BOARD_ALIAS(alias),
channel));

            try
            {
                ServosTest(ecat_dev, eni_file);
            }
            catch (Exception ex)
            {
                Console.WriteLine("{0}", ex);
            }

            EXIT_IF_FAIL("EcatClose", EcatClose(ecat_dev));
        }
    }
}
```

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