

Research Article

Design and Application of Intelligent Networking Integration System with CANopen Protocol for Tool Machine Production Line

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ABSTRACT

In this paper, the intelligent networking integration system is designed and constructed by applying the Controller Area Network (CAN)open profiles as communication protocol for tool machine production line. While the basic network management and data transmission is followed by the dictionary objects in CANopen CiA301 protocol, the axial motor of tool machine needs to implement with the motor motion control specification subjected to the CANopen CiA402 protocol. The monitoring supervisory control and data acquisition system communicates with each node with CANopen protocol through CAN Bus to complete the task of constructing and managing the entire network system.

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1. INTRODUCTION

In the industrial system, the numbers and categories of electric circuit and sensing element contained are becoming more and more complicated. The control network becomes the key technology in the industrial system [1]. Controller Area Network (CAN), this communication bus has the advantages of high noise immunity, fast transmission speed and easy installation. CAN in Automatic (CiA) organization released CANopen communication protocol for CAN application layer [2]. The basic CANopen device and communication profiles are given in the CiA301 specification released by CiA. The monitor system is mainly responsible for the controlling the nodes states and function in the network and displaying the data posted back from the nodes for the convenience of our testing whole set of network system platform. The tool machine operation control of production line is tested and realized to evaluate and verify the feasibility and performance of CANopen networking system [2].

2. COMMUNICATION PROTOCOL OF PRODUCTION LINE

2.1. CANopen

International Organization for Standardization series specifies the data link layer and physical of the CAN in open systems

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interconnection model shown in Figure 1. Many manufacturers define CAN frame by themselves for their products. However, when different manufacturers need to integrate the system, it often wastes time and costs more. Therefore, the biggest intention of CANopen is to unify the definition CAN application layer.

2.1.1. Communication object

The CANopen standard frame divides the 11-bit CAN-frame id into a 4-bit function code and 7-bit CANopen node ID. In CANopen, the 11-bit ID of a CAN-frame is known as communication object identifier, or COB-ID. COB-ID is shown in Table 1 [3].

According to communication features, CANopen divides communication objects into four categories as below:

- (i) Special function objects
 - Synchronization objects
 - Emergency objects
 - Time stamp objects
- (ii) Network Management Objects (NMT)
- (iii) Process Data Objects (PDO)
- (iv) Service Data Objects (SDO)

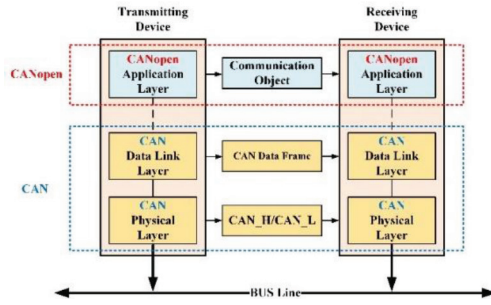


Figure 1 | Network reference model.

Table 1 | Configurations of COB-ID [4]

Object	Function code	Resulting COB-ID
NMT	0000	0
SYNC	0001	80h
Time stamp	0010	100h
Emergency	0001	81h-FFh
TPDO1	0011	181h-1FFh
RPDO1	0100	201h-27Fh
TPDO2	0101	281h-2FFh
RPDO2	0110	301h-37Fh
TPDO3	0111	381h-3FFh
RPDO3	1000	401h-47Fh
TPDO4	1001	481h-4FFh
RPDO4	1010	501h-57Fh
SDO(tx)	1011	581h-5FFh
SDO(rx)	1100	601h-67Fh
NMT error control	1110	701h-77Fh

2.1.2. Object dictionary

CANopen devices must have an object dictionary which is used for configure device parameter and communication with the device. The complete Object Dictionary (OD) consists of the six columns shown below:

- (i) Index: 16-bits object address.
- (ii) Object name: Particular index within the OD.
- (iii) Name: Simple textual description of the function of that particular object.
- (iv) Type: Information as to type of the object.
- (v) Attribute: Defines the access rights for a particular object.
- (vi) M/O: Defines whether the object is mandatory or optional.

2.2. CANopen Communication Objects

2.2.1. Network management objects

In CANopen, the NMT mainly focuses the network states of monitoring nodes as well as the function similar to the control of node operation. Figure 2 depicts the network statement of device node.

Communication objects may only be executed if the devices involved in the communication are in the appropriate communication states. Table 2 shows the communication objects and states.

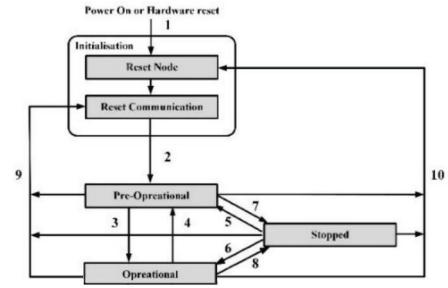


Figure 2 | NMT state machine [4]. The numbers are represent the state transition and work flow of NMT state machine in CANopen protocol.

Table 2 | States and communication objects [4]

	Initialization	Pre-operation	Operation	Stopped
PDO			√	
SDO		√	√	
SYNC		√	√	
Time stamp		√	√	
EMCY		√	√	
Boot-up	√			
NMT		√	√	√

COB-ID	Length	Byte0	Byte1	Byte2	Byte3	Byte4-7
SDO	2-8	CS	Index	Sub-Index	Data	

Figure 3 | CANopen SDO frame.

2.2.2. Service data objects

According to data transfer direction is divided into upload and download methods. Data frame of SDO consists of COB-ID, length and 2-8 Bytes data. Within 8 Bytes, Byte 0 is Command Specifier (CS) which is data length of the object, Bytes 1 and 2 are index of the object within OD, Byte 3 is sub-index of the object, and Bytes 4-7 are parameter of the object. SDO frame is shown in Figure 3.

2.2.3. Process data objects

Process data objects transmission priority is higher than SDO, so PDO is often used to transfer data in real time. PDO divided into Transmit PDO (TPDO) and Receive PDO (RPDO). TPDO is transmitted from the node to the master. In contrast, RPDO is the node to receive messages from the master. Before using PDO, set PDO Communication Parameter and PDO Mapping Parameter through SDO to complete mapping.

2.3. Device and Motion Control of CANopen

Controller area network in automatic released CiA402 protocol, and it is the standardized CANopen device profile for digital controlled motion products. Establishing device states machine for manage device. The state machine describes the device status and the possible control sequence of the drive shown in Figure 4. Within OD, Controlword (index: 6040h) could switch device status. Statusword (index: 6041h) could store device current status.

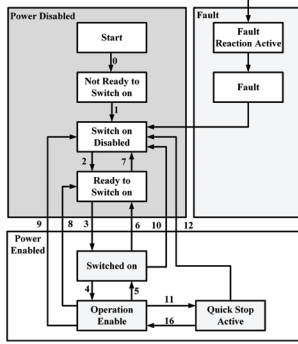


Figure 4 | Device state machine [5]. The numbers are represent the state transition and control sequence of the device state machine in CiA402 protocol.

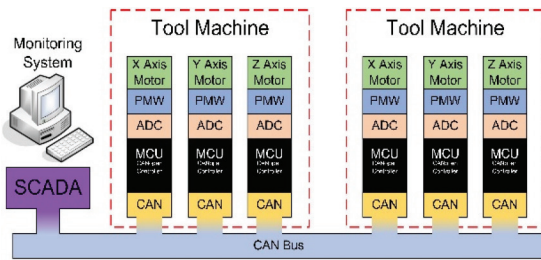


Figure 5 | Architecture of network system.

3. SYSTEM DEVELOPMENT AND DESIGN

3.1. System Networking Structure

The designed CANopen network structure is shown in Figure 5. The main network has one monitoring mode and two tool machine (six motor nodes). The main function of monitoring node is to monitor the whole CANopen network states. All equipment nodes possess CANopen protocol to establish the whole set of CANopen network system.

3.2. CANopen Controller Design

The controller firmware is designed to meet the specifications of CANopen standard agreement. CANopen communication applications are mainly based on CiA301 specification which describes NMT, SDO and PDO. This proposed controller needs to implement with the motor motion control specification subjected to the CiA402 protocol. It is also additionally equipped with a motor-specific incremental encoder to receive the motor feedback signal, so as to realize the motor speed control and high-precision positioning control [6].

3.3. PDO Mapping Schedules

In order to implement the real-time monitoring of the production line on Supervisory Control and Data Acquisition (SCADA) system, the PDO mapping is planned for each axis controller of machine devices. The PDO mapping scheduling table is shown in Table 3. Since each axial operation of tool machine is controlled by the corresponding motor, all the mapping and communication parameters of CANopen TPDO and RPDO are set in accordance

Table 3 | PDO mapping scheduling table

PDO name	Mapped object #1	Mapped object #2	Index	Data length
RPDO1	Controlword	Mode of operation	6040h, 6060h	3 Bytes
RPDO2	Target position	Profile velocity	607Ah, 6081h	8 Bytes
TPDO1	Statusword	Modes of operation display	6041h, 6061h	3 Bytes
TPDO2	Position actual value		6064h	4 Bytes
TPDO3	Digital inputs		60FDh	4 Bytes
TPDO4	RFID UID		C000h	4 Bytes

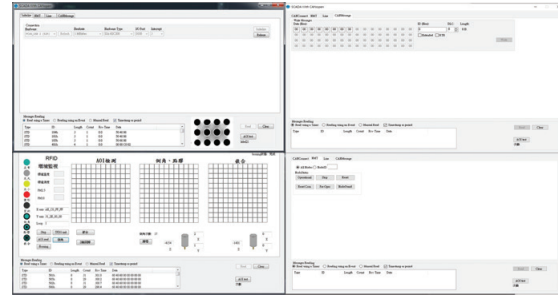


Figure 6 | Monitoring interface: SCADA system.



Figure 7 | Infix chopsticks and parts.

with the CiA402 profiles. The Controlword (6040h) and Mode of Operation (6060h) of RPDO mapping can set for the device status and device operating mode at the same time, while Target Position (607Ah) and Profile Velocity (6081h) can simultaneously deliver the commands of target position and motor speed. In addition, TPDO is used to receive the current equipment status, operating mode, actual motor position and digital inputs on SCADA system.

3.4. Monitoring System Design

The SCADA system is the main monitoring of the Bus, which monitors the entire CANopen and the network status of each node, and displays the real-time CAN data below the SCADA system interface. Its function can be divided into four tabs, Initialize, NMT, Line. The interface of SCADA system is shown in Figure 6.

4. SYSTEM INTEGRATION AND APPLICATION

4.1. Application Field of Production Line

In this study, the heterogeneous infix chopsticks are selected as the product of production line. The infix chopsticks are mainly made of stainless steel in the front section, and plastic or acrylic in the rear section, as shown in Figure 7. The production

process of infixed chopsticks is mainly completed by three major steps: (1) chamfering: reaming, (2) gluing: fixing, and (3) infixing: molding.

4.2. Design and Construction of Production Line

The production line system consists of the incoming inspection platform, two machine tools and a set of handling robot. The system architecture of the production line is depicted in Figure 8. The controllers of the two tool machines are operated in accordance with the CiA protocol. The handling robot is controlled by I/O ports on host controller.

The field planning of infixed chopsticks production line is shown in Figure 9. It presents that each machine of the working platform is quite close, and the location of each machine is mainly determined by the arm working range of Selective Compliance Assembly Robot Arm (SCARA) handling robot. The production line layout is planned according to the environmental space.

4.3. SCADA Monitoring System

The SCADA system of production line is mainly used to display the real-time situation and screen on the monitoring interface, as shown in Figure 10. In order to clearly indicate the conditions of each hole on the fixture, 144 holes on the fixture are simulated and displayed. Different icons are illustrated according to the current processing status of the infixed chopsticks at the workstation. The programming Graphical User Interface (GUI) is designed with function buttons of various situations to give commands to each workstation.

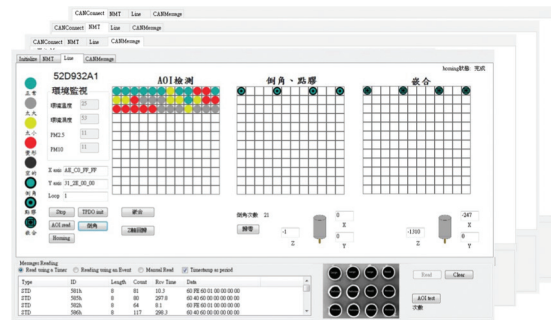


Figure 10 | GUI interface of SCADA system.

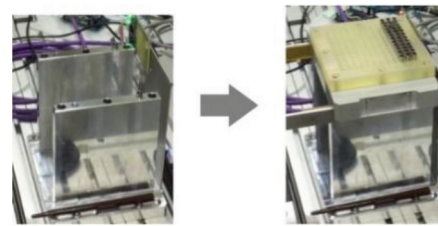


Figure 11 | RFID sensing module and operations.

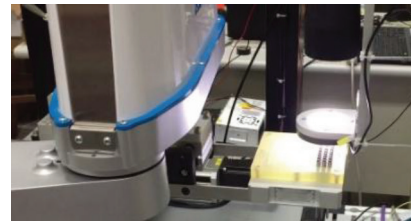


Figure 12 | Automated optical inspection system.

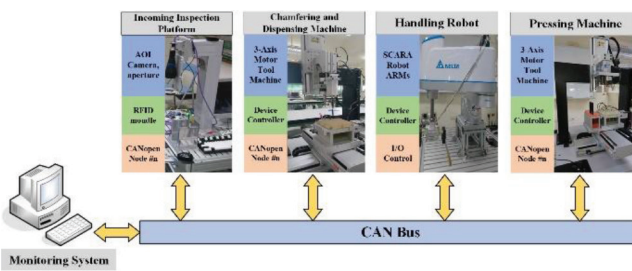


Figure 8 | System architecture of production line.



Figure 9 | Application field of production line.

4.4. Incoming Inspection Platform

The incoming inspection platform is the starting station of production line and responsible for managing whether the fixture enters the station and detecting whether the incoming is suitable for processing. The incoming inspection platform includes an Radio Frequency Identification (RFID) sensing module and an automated optical inspection system. The RFID sensing module is used to determine whether the fixture has entered the station, as shown in Figure 11. The automatic optical inspection system is introduced to inspect the processing materials, eliminate the bad incoming materials, and reduce the wear of the drilling cutter, as shown in Figure 12.

4.5. Chamfering and Gluing Machine

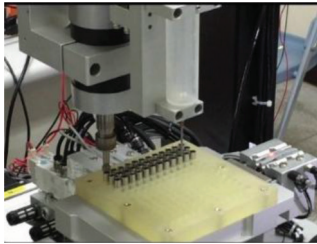
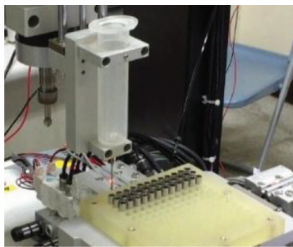
The chamfering and gluing machine is a kind of flexible manufacturing equipment with the chamfering and gluing functions in the production processes of infixed chopsticks. First, the machine completes the setting of Controlword and Mode of Operation via RPDO1 to switch the device status and operation mode. The real-time status of the machine can be viewed and checked through TPDO1. Next, the machine is switched to Homing Mode operation mode to set the

Table 4 | Related objects of Homing Mode

Index	Object	Name	Type
607Ch	VAR	Home offset	INTEGER32
6098h	VAR	Homing method	INTEGER8
6099h	ARRAY	Homing speeds	UNSIGNED32
609Ah	VAR	Homing acceleration	UNSIGNED32

Table 5 | Related objects of Profile Position Mode

Index	Object	Name	Type
6064h	VAR	Position actual value	INTEGER32
607Ah	VAR	Target position	INTEGER32
6081h	VAR	Profile velocity	UNSIGNED32
6083h	VAR	Profile acceleration	UNSIGNED32
6084h	VAR	Profile deceleration	UNSIGNED32

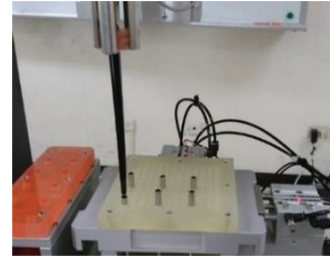
**Figure 13** | Chamfering process.**Figure 14** | Gluing process.

homing speed, homing acceleration and homing method, as shown in [Table 4](#). The machine tool must complete the homing action to ensure that the starting position of each axis is correct.

Then Profile Position Mode is selected to rotate the machine to the specified position according to the setting speed of user. SDO is used to set the acceleration and deceleration, while RPDO2 is used to set the target speed and target position, as shown in [Table 5](#). TPDO1 and TPDO2 is used to confirm whether the machine has been turned to the set target position. Through RPDO2, new target positions can be set continuously to move the three rotation axes of the chamfering and gluing machine, and cooperate with the action of the pneumatic valve to complete the chamfering or gluing process, as shown in [Figures 13](#) and [14](#).

4.6. Infixing and Molding Machine

The infixing machine implements the infixing process of infixed chopsticks. Same as the chamfering machine, SDO and RPDO1 are

**Figure 15** | Infixing and molding process.

used to complete the homing position return. Then the machine is switched to Profile Position Mode. The SDO, RPDO1 and RPDO2 are used to set continuously the movement target position, so that the motor of each axes is rotated to the correct position to achieve the infixing and molding process shown in [Figure 15](#).

5. CONCLUSION

In this paper, the CANopen node controller and the integration of intelligent production line is studied and developed by applying the CANopen protocol. The CAN bus is used to serve as the communication backbone by using CANopen as the high application-layer protocol. Moreover, the SCADA system communicates with each node through CAN Bus to complete the task of constructing and managing the entire network. Further, the control commands are released and the effective data transmission and reception processing is performed on all the nodes, so that the operator can immediately monitor the condition of the production line. In summary, the functional testing of application field is performed to evaluate the system performance of the entire system network monitoring and management.

CONFLICTS OF INTEREST

The authors declare they have no conflicts of interest.

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REFERENCES

- [1] A. Lekidis, M. Bozga, S. Bensalem, *Model-based validation of CANopen systems*, 2014 10th IEEE Workshop on Factory Communication Systems (WFCS), IEEE, Toulouse, France, 2014, pp. 1–10.
- [2] M. Farsi, M.B.M. Barbosa, *CANopen implementation: applications to industrial networks*, Research Studies Press Ltd., England, 2000.
- [3] *CAN in Automation, CANopen specification*, 1996.
- [4] CiA-301, *CANopen application layer and communication profile*, 2002.
- [5] CiA-402, *CANopen device profile drives and motion control*, 2002.
- [6] SERVOTRONIX, *EtherCAT and CANopen Reference Manuals-version 6.4*, 2017.

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