Chapter 55
Design of CAN Communication Network for Tandem Hybrid Tractor

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Abstract With the rapid development of tractors, traditional tractors are rapidly changing to electrical structures. Traditional wiring methods cannot adapt to the information exchange and sharing between the electronic control units of hybrid tractors. In order to solve these problems, the advantages of four topological structures are analyzed and compared. The two-channel CAN communication network is used to construct the whole machine CAN network architecture. Based on the SAE J1939 protocol, the communication network node is designed, and the whole machine CAN communication network protocol is developed in combination with the tandem hybrid tractor structure and the characteristics of the working conditions. The CANoe software is used to test the network and calculate the network load rate for analysis, which verifies that the communication network system can meet the requirements of real time, accuracy, and stability.

55.1 Introduction

As an indispensable tool for agricultural production, tractors are the main driving force for field operations and play an important role in the development of modern agriculture [1]. In order to cope with energy shortages and greenhouse gas emissions worldwide, energy saving and environmental protection are important themes in the field of industrial technology in the world today [2]. The energy crisis and the increasing environmental pollution have forced traditional fuel tractors to transform into hybrid tractors and pure electric tractors. The tandem hybrid tractor keeps the engine in the best working condition, reduces engine emissions and fuel consumption, and meets the needs of environmental protection and energy saving.

The rapid development of network technology and bus technology has laid a solid foundation for the development of automotive electronic technology [3]. The traditional point-to-point communication method cannot meet the information sharing, real time, and reliability among too many electronic control units [4]. Using CAN

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G. Liu and F. Cen (eds.), *Advances in Precision Instruments and Optical Engineering*, Springer Proceedings in Physics 270, https://doi.org/10.1007/978-981-16-7258-3_55

bus technology, each electronic control unit can be connected to a network, and data and information can be transmitted in a shared manner to realize networked digital communication and control functions.

CAN is a controller area network, and it is a field control bus with a two-layer protocol serial communication structure at the physical layer and the data link layer [5]. CAN bus data communication has outstanding reliability, real time, and flexibility [6]. CAN network technology is widely used in the field of tractors, providing effective solutions for real-time vehicle control and complicated wiring problems [7].

55.2 Design of CAN Communication Network Structure

55.2.1 Node Definition

Each node controller of the series hybrid tractor is connected through the CAN bus to form a vehicle control system, which controls the operation of each component separately, so as to realize the function of tractor field operation and transportation [8]. Its network nodes include: engine management system, battery management system, motor control system, ISG motor control system, gearbox control system, braking system, steering system, PTO control system, lighting system, instrument display system, lifting system, farm tools Control system, and fault detection system. As the work items of series hybrid tractors are changeable, corresponding nodes can be reserved for later expansion.

55.2.2 Analysis and Selection of Network Topology

There are four common network topologies on vehicles, namely: bus, star, ring, and mesh network topology. The characteristics of the four types of topology are:

- *Bus Structure*

The bus-type structure uses a line as the transmission medium, and all nodes in the network are connected to the bus line through specific connection hardware.

In the bus-type topology, all information in the network is transmitted on the same line, and all nodes can receive the information on the bus. The information sent by any node is based on the node as the center and is sent to both ends along the bus. This propagation mode determines the characteristics of the broadcast transmission of the bus-type network topology. It has the advantages of strong sharing of resources, simple node expansion and operation, simple and flexible structure, high network response speed, low equipment price, and high reliability. Due to the ends of the bus will be a reflection of the signal, need to be in the ends of the bus to terminal impedance with the bus impedance matching, in order to reduce the end signal reflection.

- *Star Structure*

The gateway is the centralized processing center for the information of other nodes in the network, and the information is transmitted to each node after passing through the gateway. The star structure has the characteristics of simple structure and easy construction and management, but the existence of the central point makes each node to pass through the central point before transmission, resulting in a lot of waste of lines. Once the central point fails, the entire network will stop working, which places high demands on the central point.

- *Ring Structure*

Different from the bus network, each node of the ring network is connected in series on a ring medium, and the information is transmitted in sequence, and the information is transmitted in a specific direction. After a week through the network, it returns to the sending node, and the sending node completes the recovery and deletion of the information. The advantages of the ring structure are simple structure, easier implementation, simple information transmission path, and definite time delay. However, since the information must pass through each node in turn to reach the receiving node, if there are too many nodes, the transmission of messages can be affected. And once any node fails, the whole system will be paralyzed, which will cause the problem of high network failure rate.

- *Mesh Structure*

Each node in the network is connected to each other, as long as there is a demand for information transmission, it can be connected with the corresponding line, and the line with the shortest path can be flexibly selected during the process of information transmission. The mesh structure makes maximum use of the resources of the entire network, which not only realizes the sharing of information, but also improves the efficiency of information transmission. The prerequisite for the realization of the function is to build a complex network, and only by adding a high-cost management system, there can be good communication efficiency. If there is a problem with the local area network, it will cause network failure and congestion of other nodes.

The requirements of the vehicle network topology are the characteristics of high node modularization, good expansion performance, reliability, and real-time requirements. Comprehensive comparison of various network topologies, the bus-type topology is more suitable for serial hybrid tractor on-board communication network [9].

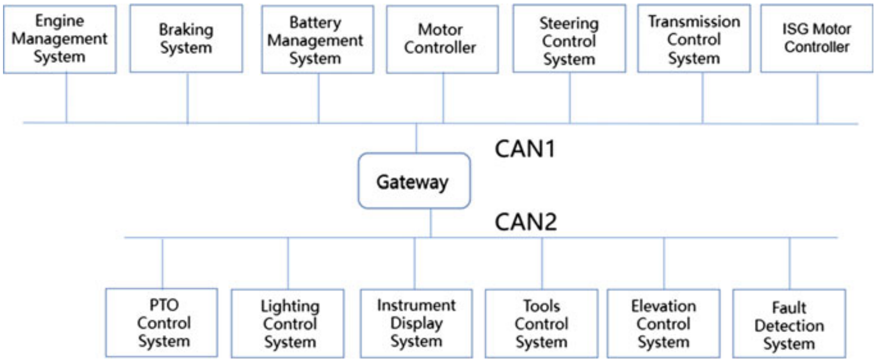


Fig. 55.1 Tandem hybrid tractor network topology

55.2.3 Communication Network Design

Because the bus-type network topology has the advantages of simple structure and high scalability, this article is based on the use of the bus-type network topology, as shown in Fig. 55.1. The communication rate of a single CAN bus is generally 125 kbit/s–1 Mbit/s. In order to ensure the real time and effectiveness of the signal acquisition of the control nodes on each CAN line, comprehensive considerations are adopted for each CAN bus rate to adopt 500 kbit/s [10]. The overall design of the CAN network is mainly to determine the number of CAN nodes and the information content that each node needs to receive and send [11]. The node engine management system, battery management system, motor control system, ISG motor control system, and gearbox The control system, braking system, and steering system are set on CAN1 to meet high real-time requirements. Set the PTO control system, lighting system, instrument display system, lifting system, farm tool control system, and fault detection system on CAN2. In order to ensure the reliability of bus communication, it is necessary to design a 120 Ω terminal resistance on the nearest and farthest controller of the system to eliminate the reflection of the signal in the communication circuit and reduce the risk of signal distortion [12].

55.3 Bus Network Communication Protocol

55.3.1 Message ID Design

Before defining the 29-bit identifier ID of each message, according to the rules of the application layer protocol, the priority, node source address, parameter group code definition is analyzed and formulated, and the communication matrix is designed. There are 8 levels of priority, and the message priority can be set from the highest

Table 55.1 Message ID

Nodes	ID	PGN	P	R	DP	PF	PS	SA
Engine management system	0 × FEDF1	00FEDF	0	0	0	FE	223	01
Battery management system	0 × FEB32	00FEB3	0	0	0	FE	199	02
Motor controller	0 × 4F11F3	00F11F	1	0	0	F1	31	03
ISG motor controller	0 × 4F18D4	00F18D	1	0	0	F1	31	04
Steering control system	0 × 4FEE85	00FEE8	1	0	0	FE	232	05
Transmission control system	0 × 4FEC76	00FEC7	1	0	0	FE	223	06
Braking system	0 × 4FEFA7	00FEFA	1	0	0	FE	250	07
PTO control system	0 × 8FEEF8	00FEEF	2	0	0	FE	240	08
Elevation control system	0 × CFEC39	00FEC3	3	0	0	FE	195	09
Tools control system	0 × CFEC5A	00FEC5	3	0	0	FE	197	10
Instrument display system	0 × 10FE6CB	00FE6C	4	0	0	FE	108	11
Fault detection system	0 × 18FEB1C	00FEB1	6	0	0	FE	177	12
Lighting control system	0 × 1CFE6ED	00FE6E	7	0	0	FE	110	13

0 to the lowest 7. In the SAE J1939 protocol, the default priority of all control messages is 3, and the default priority of all other messages, dedicated, request, and ACK messages are 6 [13]. Considering the safety, real time, and accuracy of the series hybrid tractor, the engine management system and the battery management system have the highest safety requirements, and the two nodes are set to the highest priority 0. The motor controller, ISG motor controller, steering control system, gearbox control system, and braking system nodes are set to priority 1. The priority of PTO control system, lifting system, and farm tool control system is set to 3. The priorities of the instrument display system, light control system, and fault detection system are set to 4, 6, and 7 in sequence.

The source address can be assigned by arranging the numbers in sequence, regardless of the priority, update speed, or importance of the message [14]. Define engine management system, battery management system, motor controller, ISG motor controller, steering control system, gearbox control system, braking system, PTO control system, lifting system, farm tool control system, instrument display system, fault The source addresses of the detection system and the lighting control system are 01, 02, 03, 04, 05, 06, 07, 08, 09, 10, 11, 12, and 13. The ID information of the message is shown in Table 55.1.

55.3.2 Timing Design of Message

Due to the difference between the structure and electronic control unit of the tandem hybrid tractor and the traditional tractor, the SAE J1939 protocol was referred to when designing the node message, which was redefined according to the specific

Table 55.2 Message timing

Send node	Name	Receive node	Number	Cycle (ms)	Priority
Engine management system	EI	Correspond node	1	10	0
Battery management system	BMSI	Correspond node	1	50	0
Motor controller	MCUI	Correspond node	1	50	1
ISG motor controller	ISGI	Correspond node	1	50	1
Steering control system	SCSI	Correspond node	1	50	1
Transmission control system	TCSI	Correspond node	1	50	1
Braking system	BCSI	Correspond node	1	50	1
PTO control system	PTOI	Correspond node	1	100	2
Elevation control system	ECSI	Correspond node	1	100	3
Tools control system	ATCSI	Correspond node	1	100	3
Instrument display system	IDSI	Correspond node	1	100	4
Fault detection system	MDSI	All nodes	1	100	6
Lighting control system	LCSI	Correspond node	1	100	7

situation of the tractor. According to the message timing of the tractor, as shown in Table 55.2.

55.4 CAN Bus Communication Network System Test

In order to verify the communication quality and reliability of the CAN bus communication network system, the CANoe network test tool developed by Vector is used to test on this system.

55.4.1 Message Test

According to the message ID and message sequence, a database is established through the CANoe database tool CANdb++, and simulation nodes, messages, signals, and environmental variables are added to the database [15]. Import the database into a network project with two CAN buses to test the CAN bus network. The Trace window of the CANoe software is a data tracking window, which can dynamically record all the information of the CAN network in real time. The number of messages displayed in the window is 13, the time of the test, the selection of the bus channel, the ID of the message, the data type, and the data content of each message collected. The test shows that the message is sent and received normally.

55.4.2 Communication Quality Test

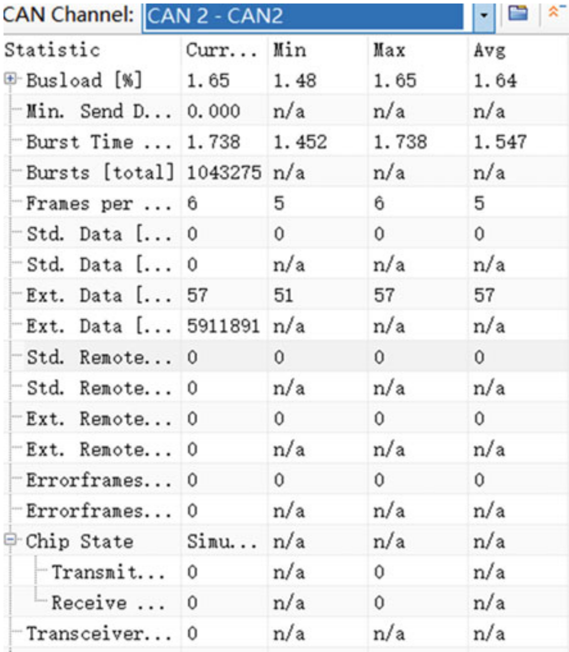
The CAN Statistics window of the CANoe software can perform statistics on the messages and get the communication quality information of the network, showing the bus load rate, message frame rate, total message frame, error frame frequency, and total error frame information, as shown in Figs. 55.2 and 55.3. The test results show that the maximum load factor of CAN1 is 6.43%, the average is 6.43%, and the minimum is 6.23%. The maximum value of CAN2 load factor is 1.65%, the average value is 1.64%, and the minimum value is 1.48%. The bus load rate of CAN1 and CAN2 is lower than the standard safety threshold of 30%, no error frame occurred during the test, and the system performance is stable.

Fig. 55.2 CAN1 network load rate

CAN Channel: CAN 1 - CAN1

Statistic	Curr...	Min	Max	Avg
Busload [%]	6. 43	6. 23	6. 43	6. 43
Min. Send D...	0. 000	n/a	n/a	n/a
Burst Time ...	2. 032	2. 032	2. 032	2. 032
Bursts [total]	2086550	n/a	n/a	n/a
Frames per ...	7	7	7	7
Std. Data [...	0	0	0	0
Std. Data [...	0	n/a	n/a	n/a
Ext. Data [...	220	213	220	220
Ext. Data [...	2295...	n/a	n/a	n/a
Std. Remote...	0	0	0	0
Std. Remote...	0	n/a	n/a	n/a
Ext. Remote...	0	0	0	0
Ext. Remote...	0	n/a	n/a	n/a
Errorframes...	0	0	0	0
Errorframes...	0	n/a	n/a	n/a
Chip State	Simu...	n/a	n/a	n/a
Transmit...	0	n/a	0	n/a
Receive ...	0	n/a	0	n/a
Transceiver...	0	n/a	n/a	n/a

Fig. 55.3 CAN2 network load rate



CAN Channel: CAN 2 - CAN2

Statistic	Curr...	Min	Max	Avg
Busload [%]	1. 65	1. 48	1. 65	1. 64
Min. Send D...	0. 000	n/a	n/a	n/a
Burst Time ...	1. 738	1. 452	1. 738	1. 547
Bursts [total]	1043275	n/a	n/a	n/a
Frames per ...	6	5	6	5
Std. Data [...	0	0	0	0
Std. Data [...	0	n/a	n/a	n/a
Ext. Data [...	57	51	57	57
Ext. Data [...	5911891	n/a	n/a	n/a
Std. Remote...	0	0	0	0
Std. Remote...	0	n/a	n/a	n/a
Ext. Remote...	0	0	0	0
Ext. Remote...	0	n/a	n/a	n/a
Errorframes...	0	0	0	0
Errorframes...	0	n/a	n/a	n/a
Chip State	Simu...	n/a	n/a	n/a
Transmit...	0	n/a	0	n/a
Receive ...	0	n/a	0	n/a
Transceiver...	0	n/a	n/a	n/a

55.4.3 Calculation of Bus Load Rate

This system uses two CAN bus networks, the baud rate is 500 kbps, the total number of binary transmissions within 1 s is 500,000 bit, the maximum number of bits required for a frame of message is 128 bit, the maximum that CAN1 and CAN2 can send within 1 s The number of messages is 500 000/128 = 3906. According to the sending frequency of the messages, the number of messages sent within 1 s can be calculated as.

CAN1: $(1/10 + 1/50 \times 7) \times 1000 = 240$

CAN2: $1/100 \times 5 \times 1000 = 50$

CAN1 network load rate: $240/3906 \times 100\% = 6.14\%$

CAN2 network load rate: $50/3906 \times 100\% = 1.28\%$.

There is a certain error between the calculated bus network load rate and the network load rate tested by the software, but the error is small. Considering that the calculation is the result of an ideal state, there may be queuing and interference in the transmission process when the actual message is sent. They have a good consistency.

55.5 Conclusions

In view of the current situation in my country where there is little research on the communication network of the hybrid tractor vehicle control system, tandem hybrid tractors are taken as the research object, the network topology structure is analyzed, and the CAN bus network structure design is carried out. According to the structure and actual requirements of the series hybrid tractor, the CAN network communication protocol was developed on the basis of the SAE J1939 protocol, and the specific information of the messages and nodes was designed. Using CANoe software to test the Controller Area Network system, it verifies the real-time and accuracy of the communication system. It provides reference for the development of services hybrid tractors in China.

Acknowledgements This article is one of the phased achievements of the Open Project of the State Key Laboratory of Tractor Power Systems (SKT2021002).

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