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Design and test of a distributed control system of weeding robot based on multi-STM32 and CAN bus

Design and test of a distributed control system of weeding robot based on multi-STM32 and CAN bus

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Abstract. Aiming at the problems of a single control mode, complex signal line, serious interference and poor system stability of a traditional weeding machine, a distributed control idea was proposed. Based on STM32 as the main control chip, each control unit realizes motion control, detection control, command control, and the terminal was displayed in a centralized manner. Based on ISO11783 protocol, according to the actual requirements of the weeding robot, the CAN bus communication protocol was improved and formulated to form a distributed control system. The system can completely realized all the actions of the weeding robot. 1. Motion controls: robot forwards, backwards, turning and weeding knife up or down; 2. Detection feedback: a power chassis climbing angle calculation and weeding knife speed self-adjustment, battery power, engine fuel capacity display; 3. Control command input functions. The test results had shown that the control system is stable, responsive solid, design specifications. It could meet the requirements of practical application. Meanwhile, the real-time accuracy and reliability of a CAN bus application in the agricultural production control system were verified.

1. Introduction

In the process of modern agricultural development, weeding in the field has become a major problem. Traditional weeding methods mainly rely on manual and herbicides. Among them, manual weeding has high labor intensity and high cost. Herbicide weeding pollutes the environment and destroys the ecology. Mechanical weeding had gradually become an essential way of weeding. With the development of automation and intelligence in agricultural equipment, various electronic control units had been added to mechanical weeding machines to meet the real-time and accuracy of signals and improve signal utilization[1]. In addition, due to the harsh working environment of the weeding robot and the scattered positions of the various actuators and sensor devices, the traditional electrical system must integrate the signal connection lines to the control board, resulting in a bloated wiring system[2].

In this paper, the weeding robot adopted a distributed control method. The control system was divided into a manual operation unit, a chassis drive control unit, a weeding knife adjustment unit, and a detection unit[3]. Each control unit used STM32F103 single-chip microcomputer to process information, reducing the main controller chip and improving the system's overall performance[4]. Each unit adopted Controller Area Network for communication, which had strong anti-interference ability, strong arbitration fault tolerance and low cost[5].

This study took the weeding robot studied by the laboratory research group as the research object, modularized each function of the weeding robot control system, designed a distributed control system based on the CAN bus[6], and developed the CAN bus communication protocol based on ISO11783, and built the single-chip CAN[7]. The network platform was used to control the weeding robot. Finally, the actual vehicle test was used to verify better the problem of system information transmission and processing[8].

2. Mechanical Structure Of Weeding Robot

In this paper, the overall mechanical structure of the weeding robot included the main frame, the variable mowing height mechanism, the power transmission mechanism, the electrical control part and the sensor part. (1) The main frame was equipped with a drive mechanism, a variable mowing height mechanism, an electrical control part and a sensor. The drive mechanism was directly driven by two DC motors. The steering of the weeding robot was realized by the differential rotation of the rear two motors. (2) The power transmission mechanism and generator were installed on the variable cutting height mechanism, and the height of the cutting knife could be adjusted according to the depth of the grass through the parallelogram structure driven by the linear motor. (3) The power transmission mechanism provided power to the cutting knife and installed a sensor to feedback the rotation speed of the cutting knife to the controller. (4) The electrical control part contained the battery, STM32 control board and necessary control circuits. (5) Sensors included cutter speed sensor, climbing angle sensor, wheel speed sensor and so on.

3. Distributed Control System Design

CAN Bus is a high-speed field bus, data communication has outstanding reliability, real-time and flexibility. The CAN controller worked in a multi-master mode. Each node in the network could compete to send data to the bus by using a bit-by-bit arbitration with a lossless structure according to bus access priority. The CAN protocol abolished the station address coding and replaces it with communication data encoded, which allowed different nodes to receive the same data simultaneously. These characteristics made the data communication between the nodes of the CAN bus network had a solid real-time performance, and it was easy to form a redundant structure, which improved the reliability and flexibility of the system. The control system of the weeding robot consists of driving control, cutting height adjustment control, cutting knife speed adjustment control, vehicle body inclination detection, battery power detection, engine oil detection and CAN bus. The topology structure of the weeding robot CAN bus system is shown (see Figure 1). In this study, the weeding robot used a gasoline engine to provide power for the cutter, while the gasoline engine drove a generator to charge the power source. The rear-wheel-drive used two brushless DC motors. This solution could improve the efficiency of the weeding robot and reduce the complexity of the weeding robot structure but put forward higher requirements for the control system of the weeding robot.

The motion control unit was used to control the drive unit of the weeding robot. The IO port of STM32 controlled the two brushless DC motors to drive the forward, backward and steering of the weeding robot. The front wheel of the weeding robot was a universal wheel, and the robot steering was realized by the differential speed of the left and right motors on the back side. The header cutter controls unit controlled the height of the header and the speed of the cutter. STM32 controlled the expansion and contraction of the electric push rod to adjust the height of the header, and controlled the speed of the cutter by controlling the steering gear to control the engine throttle.The steering gear controlled the engine throttle to control the speed of the cutting tool. The sensor detection feedback unit was used to detect the status of various sensors, including wheel speed sensor, cutter speed sensor, cutting table height sensor and car body Angle sensor. STM32 read the status of each sensor and fed it back to other control units through the CAN bus communication network. The display unit communicated with each control unit through the CAN bus to collect the data of the whole machine, and displayed it through the panel. The information displayed on the screen included vehicle speed, cutting table height, cutter rotation speed, vehicle body inclination, power supply quantity and gasoline oil quantity. The key operation unit and the remote control operation unit were arranged with multiple keys, which were used to input action commands of the weeding robot.

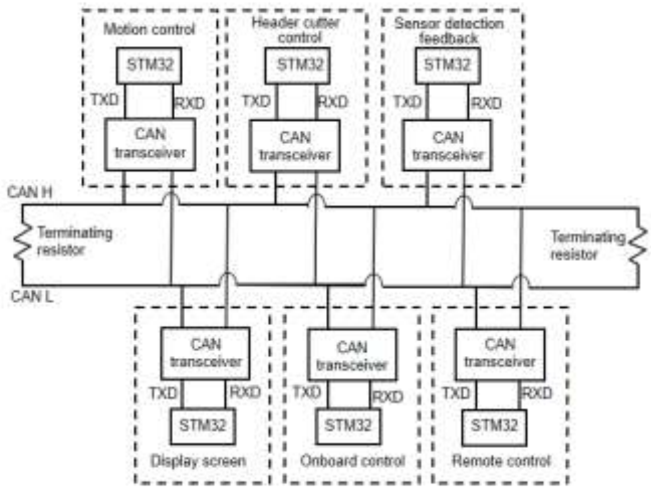

Figure 1. System Communication Network Topology Diagram.

3.1. Hardware design of control system

The main control chip of each control unit in this design was STM32C8T6. Its core was a 32-bit ARM Cortem-M3 CPU with a maximum operating frequency of 72MHz. The memory was 128K bytes of flash memory program memory and 20K bytes of SRAM. The chip totaled Lead 37 GPIO, 1 CAN interface, working voltage 2V~3.6V, working temperature-40℃ ~80℃, support LCD with SPI interface. With low cost, high speed, high cost performance, and rich interfaces, it could meet the actual need[9].

Power Circuit The onboard battery provided a 24V power supply, which was reduced from the LM2576HV multi-channel step-down module to 5V and 3.3V. At the same time, an anti-reverse connection diode and filter circuit were added to improve the safety and stability of the circuit, which CAN supplied power for each control unit and CAN transceiver.

CAN transceiver adopted the TJA1050 high-speed isolation transceiver module. Based on the ISO11783 protocol, a CAN bus communication protocol was developed. It CAN transmit data on two bus cables with differential voltage with a bit rate of up to 1Mbit/s. Nodes without power on will not cause disturbance to the bus. At least 110 nodes can be connected, CAN2.0 was supported, and the longest communication distance was 1km, which met the design requirements and provided the possibility for subsequent expansion. The communication circuit diagram is shown (see Figure 2).

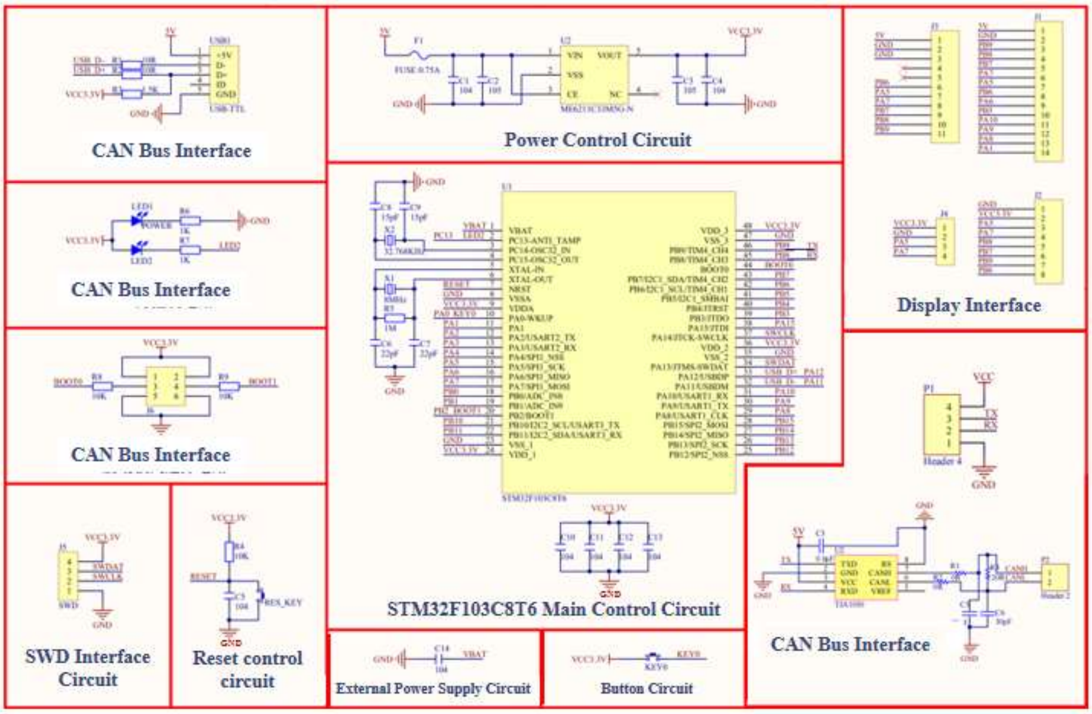

Figure 2. Communication Circuit Diagram

The motion operation unit received the CAN bus data, and the STM32 single-chip microcomputer controlled the drive motor to execute the driver command. The required voltage of the driver was 24V. The 24V voltage of the onboard battery needed to be increased to 48V through a transformer. It adopted a Magendi high-power DC motor driver and DC brushless motor. Built-in Hall sensor, the driver could calculate the current motor speed according to the combination change of the output signal of the Hall sensor and realized the closed-loop control of the motor. The brushless DC motor selected 80BL110S50-430TKA, the reducer was a planetary reducer of PX86N030S0, and the reduction ratio was 30.

The header cutting knife control unit received CAN bus data, and the STM32 drove the electric push rod and the steering gear to adjust the height of the header and the cutting speed of the cutting knife respectively. The L298N motor drive module was used to control the expansion and contraction of the electric push rod. The electric pushed rod comes with a limit device. It stopped automatically when it extends or retracts to the limit position. The electric push rod used Huifeng Electric's HF-TWG-DW-100-12-10, the stroke was 100mm, the maximum thrust was 750N, the working voltage was 12V, and the voltage was reduced by multiple channels. The module was converted to 12V to supply power; the speed of the weeding robot cutter was the key to the control of the whole machine. In this study, the weeding robot cutter was powered by a gasoline engine. The gasoline engine was four-stroke 8.5 HP, and the steering gear was used to control the engine's throttle line.

Sensor detection feedback collected the real-time data of the whole machine, and sent it to each control unit through the CAN bus. When the whole machine is abnormal, an alarm will be issued, and the data of the speed sensor, angle sensor, oil quantity, electricity sensor, cutter speed sensor and header height sensor will be displayed on the LCD display in real-time.

3.2. Control System Software Design

The control system was divided into drive control, header cutter control, sensor detection feedback and adjustment, sensor detection alarm, key operation, remote operation and display screen. After each system was powered on and initialized, the sensor detected the status of the whole machine and sent it to the display screen through the CAN bus. After starting the engine, the whole machine entered the working state, and the weeding robot could be controlled remotely through the handle or the onboard buttons.

The weeding robot has an alarm protection mechanism to avoid the risks of chaotic motion state, motion reaching limit and motor stuck. There are mainly the following aspects:

- When the emergency switch is pressed, all actions of the weeding robot will stop.
- When the robot is driven by obstacles, cutter rotation encounters hard objects, and the cutting platform lifting mechanism is stuck by foreign objects, the motor is stuck for more than 2 seconds, and onboard alarm alarms and stops.
- When the overall body inclination of the robot is greater than 30 °, the machine can be avoided overturning, and the onboard alarm will alarm and stop the machine.

When the electric quantity and oil quantity are less than 5%, the onboard alarm will remind.

4. CAN Bus Communication Protocol

4.1. CAN bus structure

In this study, the design of the weeding robot was different from the traditional agricultural machinery equipment in the power unit and execution control part, so based on the ISO11783 protocol, according to the actual needs of the weeding robot, the weeding robot CAN bus communication protocol was improved and developed[10]. The ISO11783 mainly defined the electrical connection, communication protocol and message structure between ECU and network bus[11]. The weeding robot protocol was divided into the application layer, network layer, data layer and physical layer. The role of the physical layer was to establish the transmission of information through electrical circuits; the data layer is based on CAN2.0B, which defined the method and format of information transmission and storage for each control unit. The format provided control for sending CAN data frames; the function of the network layer was to manage different network interconnections, and the application layer provided detailed parameter definitions; the CAN bus communication of the weeding robot mainly provided the highest level for the remote control message sequence, reducing The small weeding robot had a time delay, which increased the safety of the weeding robot. Other messages were set with the appropriate priority according to the corresponding real-time requirements.

4.2. Data Frame Format

The CAN bus data frame could be divided into standard frame and extension frame. The CAN bus protocol of the weeding robot followed ISO11783 to define the communication strategy only for the extended frame, in which the extended data frame defines the data transmission priority, transmission mode, communication requirements, arbitration method, error detection and so on.

The extended data frame format was shown (see Figure 3). The CAN bus arbitration field included 29 bits identifiers, of which 11 bits were the basic ID, and 18 bits were the extended ID. In the ISO11783 standard, the first 3 bits of the 29 characters determine the priority P of the message during the arbitration process. In the bus, "0" was dominant and "1" was recessive, which were divided into eight levels. P=000 was the highest level, P=111 was the lowest level. When recessive and dominant messages were sent at the same time on the bus, dominant messages were sent first. The CAN bus arbitration field is shown (see Figure 4). The reserved bit R will be used for international standards and will be sent by ' 0 ' in one byte. The data page DP was used to select identifiers in two-page parameter groups, Page 0 contains all messages that are now defined, and page 1 was It will be expanded in the future and will be allocated after page 0 was used up. PDU formats (PF) were used to determine the format of the protocol data unit. According to the value of PF, it could be divided into two types: PDU1 and PDU2.When PF < 240, PDU1 format provided parameter group communication suitable for sending to a specific target. When PF ≥ 240, PDU2 format was used as parameter group communication for global messages. SRR was a recessive bit in the communication process. The specific PDU could use the target address or group expansion, and its definition depended on other PDU formats, which were determined by PF data. The target address refers to the specific address sent by the message, which was ignored by other controller addresses. Only ECU that met the purpose can listen and respond. The global address (255) required all the controller units to decode this data frame. The expansion group was to represent more parameter groups, each data page 56×16=4096 group expansion, PDU1 had 240 parameter groups, the total number of parameter groups that could be represented was (240+(16×256)) ×2=8672. In a CAN network, only one device could be assigned to a specific source address.

	Arbitration frame 32-bit					Control field 6-bit			Data field 64-bit	CRC field 16-bit		Response field 2-bit		
SOF	Identifier	SRR	IDE	Identifier Ext	RTR	r1	r0	DLC	Data field	CRC	CRC Delimiter	Response gap	Response delimiter	EOF
1	11	1	1	18	1	1	1	4	0-64	15	1	2		7

Figure 3. Expand The Data Frame

	Basic identifier 11-bit					Extended identifier 18-bit		
Priority	Reserved	Data page	PDU format	SRR	IDE	PDU format	PDU specific	Source address
P	R	DP	PF			PF	PS	SA
3位	1位	1位	6位	1	1	2位	8位	8位

Figure 4. CAN Bus Arbitration Field

4.3. System Communication Protocol

According to the actual requirements of the weeding robot, all the control instructions were defined, and the appropriate sending cycle and priority were set according to the real-time requirements of the instructions. The system had six nodes, each control unit through the CAN bus network feedback information, through the CAN bus network, and controls the movement of each part of the mechanism through independent calculation of each control unit.

According to the CAN network protocol of the weeding robot, the message sequence table of each node was formulated, as shown in table 1.

Table 1. Timing Table Of Node Message

Send	Message name	Receiving node	Number of frames	Priority
Onboard button controller	CK	All nodes	2	1
Remote Joystick Controller	RC	All nodes	2	2
Drive Motor Controller	DM	Corresponding node	1	3
Header Linear Motor Controller	CEM	Corresponding node	1	3
Steering Gear Oil Line Controller	SGL	Corresponding node	1	3
Angle Sensor Controller	AT	Corresponding node	1	4
Drive Motor Speed Sensor Controller	MRS	Corresponding node	1	4
Cutter Speed Sensor Controller	CSS	Corresponding node	1	4
Header Height Sensor Controller	CHS	Corresponding node	1	4
Battery Energy Manager	BMS	Corresponding node	1	4
Fuel Tank Fuel Manager	TFM	Corresponding node	1	4
Alarm Light Controller	AL	All nodes	2	3

The 29-bit identifier was redefined according to the priority of the message, the Data frame format was defined by the Protocol Data Unit (PDU), and the message ID number (hexadecimal) was determined according to the target address, source address, type and other elements of the message information, and the defined format was shown in table 2.

Table 2. The Format Of The Message ID Number Defined

Message Name	Priority	Reserved	Data Page	PDU Format	PDU Specific	Source Address	Message ID
CK	001	0	0	11110000	00000000	00000011	0x04F00003
RC	010	0	0	11110001	00000000	00000100	0x08F10004
DM	011	0	0	00001000	00000001	00000101	0x0C080105
CEM	011	0	0	00000010	00000001	00000110	0x0C020106
SGL	011	0	0	00000011	00000001	00000110	0x0C030106
AT	100	0	0	00000100	00000011	00000111	0x10040307
MRS	100	0	0	00000111	00000011	00000111	0x10070307
CSS	100	0	0	00001110	00000011	00000111	0x100E0307
CHS	100	0	0	00001111	00000011	00000111	0x100F0307

BMS	100	0	0	00010000	00000011	00001000	0x10100308
TFM	100	0	0	00110000	00000011	00001000	0x10300308
AL	011	0	0	00000001	00000011	00000111	0x0C010307

5. Machine Construction And Test

Building a CAN bus distributed control test platform (see Figure 5). CANoe software was used to test the message. The maximum and minimum of the total load of the system were 10.65% and 9.94%, and the average load was lower than the upper limit of the load rate of 70%, indicating that the average load was at a safe level. The test platform had a total of six nodes, which could be obtained through the comparison and analysis of experimental data. The message displayed between the controllers was consistent with the design message ID, and the corresponding message could correctly display the changed message data. A CAN bus control system could meet the reliability and real-time requirements of information transmission.

To verify the feasibility and stability of the CAN bus distributed control system of the weeding robot, an experimental vehicle-mounted test was carried out on the weeding robot[12] (see Figure 6). The focus was on the actual test of the control of the cutting table, the control of the cutter, and the steering control of the weeding robot. After being carried and verified by field experiments, the control system had reliable data transmission and could realize various functions of the weeding robot.

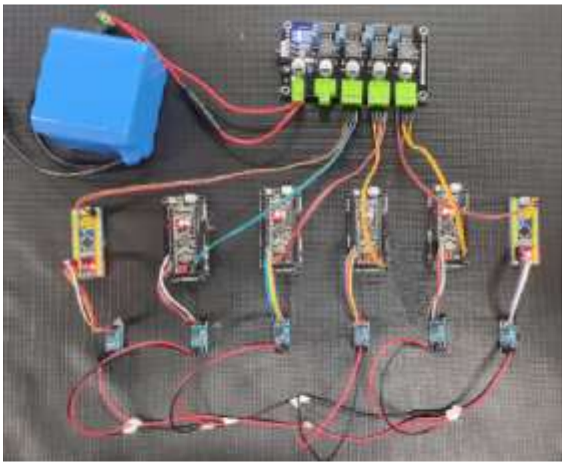

Figure 5. CAN Bus Distributed Control System

Figure 6. On-board Test Of Weeding Robot CAN Bus

6. Conclusion

According to the functional communication requirements of the weeding robot, this study designed the message timing sequence and message ID of the weeding robot based on the ISO11783 protocol.

By building a CAN bus distributed control test platform, the signal of the whole machine of the weeding robot was tested. The experiment proved that the CAN bus communication network of the weeding robot was accurate and reliable, and it could complete various command actions.

According to the structural characteristics of the weeding robot, a CAN bus distributed control system was designed and developed, which combined the powerful computing power of STM32 with the security and stability characteristics of a CAN bus. The system had the characteristics of fast response speed, high transmission reliability, strong ductility and so on. The control system included the motion, detection, control and display functions of the entire weeding robot.

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