Design of wind tunnel temperature and humidity data acquisition system based on CAN/SimpliciTI hybrid network

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Abstract. In order to obtain the temperature and humidity information of the Test section in the low-speed flue gas wind tunnel in real time, a low-power wind tunnel temperature and humidity data acquisition system based on CAN/SimpliciTI hybrid network is designed. The CAN network is used as the main network, while the SimpliciTI low-power wireless sensor network as the sub-network. The terminal ED nodes of sub-network acquire the ambient temperature and humidity information of the location and then transmit them to the gateway node by wireless mode. In the gateway node, the SimpliciTI messages are converted into CAN messages, and finally, they are delivered to the main network. The host computer communicates with the gateway node through the CANalyst-II protocol analyzer, and finally gets the temperature and humidity information of each ED terminal. Compared with the traditional bus type communication system, the system has the advantages of less wiring, simple network hardware, low power consumption, and convenient maintenance.

1. Introduction
With environmental protection and emission reduction attracting more and more attention from the government and the public, how to measure the amount of greenhouse gas emissions of fixed pollution sources has become an urgent problem for environmental protection workers. At present, the flowrate measurement for stationary source mainly depends on the velocity-area method. The velocity of each point in the measured section is obtained through the flow velocity instrument, and the instantaneous flowrate of the section is obtained by combining with the area of the measured section which the temperature and humidity correction should also be taken into account. In order to ensure the accuracy of the flow velocity meter, the low-speed flue gas wind tunnel with variable temperature and humidity is designed as the calibration device of the meter. A wireless low-power temperature and humidity data acquisition system based on CAN/SimpliciTI hybrid network is developed to accurately acquire the temperature and humidity in the test section of the low-speed flue gas wind tunnel.

2. The overall design of the temperature and humidity data acquisition system
In this paper, based on the SimpliciTI protocol's communication mechanism, frame format and message transmission mode, a low-speed flue gas wind tunnel of temperature and humidity data acquisition system based on CAN/SimpliciTI hybrid network is formed, where the CAN network is the main network and wireless SimpliciTI network is the sub-network.
2.1. The CAN bus technology
The CAN(Controller Area Network) protocol is a serial bus communication protocol developed by BOSCH automobile company in the 1980s. In the beginning, it mainly aimed at real-time data transmission between electric control units of vehicles. After 30 years' development, it is widely used in various fields such as testing instruments and industrial robots. The frame format of CAN message used in this design is CAN2.0B standard frame format which contains 0~8 byte data and 11-bit identifier [1, 2], as shown in figure 1.

![Figure 1. The CAN2.0B standard frame format with 11-bit identifier.](image)

Like most of the network communication protocols, the CAN protocol follows the OSI model specification. The protocol can be divided into the physical layer and the data link layer. The physical layer is responsible for defining the signal transmission method in the network, while the medium access layer of the data link layer is responsible for transmitting, answering, bus arbitration, and the logical link control layer mainly provides related services for remote data requests.

2.2. The SimpliciTI wireless communication technology
The SimpliciTI protocol, developed by Texas Instruments in the early 2000s, mainly focuses on the application for low power and short-distance wireless communication, which was originally mainly used as a supplement to ZigBee wireless communication protocol [3]. According to its communication mechanism, the devices in the network can be divided into AP (data center), ED (terminal) and RE (range extension). As a network host, AP is always at work making the whole network run normally and receiving data from ED at any time; while ED is responsible for data acquisition and transmission and receiving instructions from the AP. The SimpliciTI protocol has a more variable topology, such as point-to-point topology, star topology and string topology. Because there are only a few ED nodes in this design, two kinds node of AP and ED are defined. And the star network topology is adopted for data communication.

Unlike other communication protocols, this protocol does not have typical data link layer and physical layer. Instead, it is based on the radio frequency layer and board level support package in the logical layer to receive and transmit data between different nodes. The application layer is used as an interface for engineers to develop the basic application of data acquisition and controlling of actuators.

2.3. The scheme design of data acquisition system based on CAN/SimpliciTI hybrid network
Based on the above analysis, the temperature and humidity data acquisition system of the flue gas wind tunnel should include the main network—CAN network and the sub-network—SimpliciTI wireless network. The CAN/SimpliciTI gateway node is responsible for the interconversion of the two message frames. Also, the ED terminal nodes and CANalyst-II protocol analyzer, produced by Zhou Ligong, which simulates the master controller of the CAN network, should also be included in the data acquisition system. Through the CANalyst-II protocol analyzer medium, the host computer software can communicate with CAN/SimpliciTI gateway node to control the ED nodes in the SimpliciTI wireless sub-network to acquire the temperature and humidity data at different locations in the wind tunnel. The block diagram of temperature and humidity data acquisition system of the wind tunnel based on CAN/SimpliciTI hybrid network is shown as in figure 2.
3. The hardware circuit design

3.1. The circuit design of CAN/SimpliciTI gateway node

The CAN/SimpliciTI gateway requires dual interfaces in the hardware for both CAN bus and SimpliciTI wireless transceiver. The MSP430F2274 low-power 16-bit MCU designed specifically for the SimpliciTI protocol application is selected as the core CPU of CAN/SimpliciTI gateway [4, 5]. Connecting it with the CC2500 medium frequency transceiver, the gateway (AP node) can communicate with the ED node in the SimpliciTI sub-network. While connecting it with the SJA1000 CAN bus controller and TJA1050 CAN transceiver, the gateway (AP node) can communicate with the CAN main network. The block diagram of CAN/SimpliciTI hybrid network gateway is shown in figure 3.

3.2. The circuit design of CAN bus communication module

The SJA1000 CAN controller can assist the core CPU to realize the functions of CAN protocol interface logic, message caching, message frame packaging, message verification, etc. Then the physical transmission of CAN message frames to CAN network is completed with the TJA1050 CAN transceiver. The circuit block diagram of CAN bus communication module of gateway node is shown as figure 4.
3.3. The circuit design of ED terminal for temperature and humidity data acquisition

The MSP430F2274 low-power 16-bit MCU is also chosen as the CPU of the ED terminal considering the convenience for the software development of the node. And the CC2500 medium frequency transceiver is also connected with the CPU to transmit-receive the data in the wireless SimpliciTI sub-network. In addition, the composite sensor AM2302 is selected in this design to measure the environmental temperature and humidity. The temperature measurement range of the sensor is from 40 °C to 80 °C, and the accuracy of the measurement is ±0.5 °C, while the accuracy of the humidity measurement is ±2%RH when the temperature is between -20 °C and 80 °C. The circuit diagram of temperature and humidity acquisition node(ED) is shown as figure 5.

4. The software design of the data acquisition system

In this design, the software of the gateway node and ED node is programmed based on the EW430 workbench, which has the advantage of friendly software programming environment and is in support of JATG program download and online debugging. The host computer based on Labview virtual instrument can communicate with the ED node with the assistance of the CANalyst-II protocol analyzer, and then display and record the temperature and humidity of each location in the wind tunnel.

4.1. The software design of CAN/SimpliciTI gateway node

The main function of the CAN/SimpliciTI gateway node software is to coordinate with the hardware to transform message frames between CAN and SimpliciTI. And as the AP node of the SimpliciTI subnetwork, it is also responsible for receiving the data from the ED nodes and for controlling the access and sleep of all ED nodes in the subnetwork. In the program design, the definition of operating mode, communication rate, message filtering mode and interrupt mode of CAN node in the network is set by configuring relevant modules of SJA1000. The Bool CANTransmitMsg and Bool CANGetMsg are used to transmit and receive the CAN message from the main network. The control of SimpliciTI sub-network by the gateway is mainly completed through API functions such as BSP_Init, SMPL_Init and SMPL_LinkListen, which can assign the addresses of each ED node, allow the entrance of new nodes and monitor the wireless network information. The complete transmission process of data information in the CAN/SimpliciTI hybrid network is as follows: when the gateway node receives the message from the CAN network, it first needs to analyze whether the message is the control message or the information query message. For the latter, the SMPL_LinkListen function should be called to
receive temperature and humidity data of the specified node and store in the corresponding data cache. Then the data should be analyzed and converted into CAN message format, and the Bool CANTransmitMsg function is called to transmit the CAN message to the CAN network. The software flow chart of data transmission in CAN/SimpliciTI hybrid network is shown as figure 6.

Figure6. The Software flow chart of data transmission in CAN/SimpliciTI hybrid network.

4.2. The software design of the ED node in sub-network

The function of the ED node in the SimpliciTI wireless sub-network is to acquire the temperature and humidity data and transmit them to the gateway node. It also should receive the control or query message from the AP node, which makes itself join the network, transmit data message and sleep or wake up. The program flow chart of ED node data acquisition and transmission is shown in figure 7. After the AP node initialization the network, ED node joins the network and waits for the port allocation message from the AP node. After the port configuration is completed, the ED node will initialize its temperature and humidity data acquisition port and gather the temperature and humidity data through AM2302 in real time, and then transmit the data to the gateway node. No work will be done in the sleep mode.

Figure7. The software flow chart of temperature and humidity acquisition node(ED).
4.3. **The software design of Labview virtual instrument for the host computer**

The control of host computer on CAN network and the real-time acquisition of wind tunnel temperature and humidity data are realized through the medium which the CANalsyt-II protocol analyzer simulates the CAN network master controller. This protocol analyzer is connected with industrial computer through the USB interface and able to analyze and process message frames of CAN2.0A and CAN2.0B. It is quite suitable for the data acquisition and analysis of CAN network. With the help of Virtual CAN Interface function (VCI) and ControlCAN.dll, it is easy for the Labview software to control the CANalsyt-II protocol analyzer. The VCI function is mainly used to initialize CAN analyzer (VCI_BOARD_INFO), and device information (VCI_INIT_CONFIG), and define the CAN message frame structure (VCI_CAN_OBJ), etc; while the ControlCAN.dll dynamic link library function is mainly used to open or close CAN devices (VCI_OpenDevice, VCI_CloseDevice), initialize CAN network (VCI_InitCan) and transmit or receive CAN message of specified devices (VCI_Transmit, VCI_Receive). In the Labview block diagram, the event structure is embedded into the while loop structure to form the CAN message transmitting loop, CAN message receiving loop and the front panel interface event processing loop. The three loops run independently and concurrently, but the front panel event processing loop is taken as the main loop, which can communicate with the other loops. The block diagram of CAN message transmitting loop is shown as figure 8.

5. **The experimental verification**

To verify the reliability and practicability of the low-speed flue gas wind tunnel temperature and humidity acquisition system based on CAN/SimpliciTI hybrid network, the 3 experimental ED terminals were placed 120 degrees apart each other in a circle on 3 fixed rod, where the circle lay in the central section of wind tunnel test section and which radius was 0.4 times of wind tunnel test section radius. In addition, a calibrated hand-held infrared thermometer and a humidity probe were installed on the rods to test the measurement results of temperature and humidity data acquisition system developed in this paper. The temperature of the wind tunnel test section was set 20 ℃ and 30 ℃ respectively; while the relative humidity of it is set 45%RH and 60%RH respectively. The test results are as follows:

| Table 1. The test result of the temperature and humidity data acquisition system with temperature 20 ℃ and relative humidity 45%RH |
|--------------------------------------------------|
| **Test** | **humidity %RH** | **temperature ℃** | **Relative error (%)** | **Test** | **humidity %RH** | **temperature ℃** | **Relative error (%)** |
|---------|------------------|-------------------|------------------------|---------|------------------|-------------------|------------------------|
| ED1     | 44.7             | 44.0              | 0.7                    | ED1     | 44.7             | 20.8              | -0.1                   |
| ED2     | 44.3             | 44.6              | -0.3                   | ED2     | 44.3             | 20.7              | 0                     |
| ED3     | 44.1             | 43.5              | 0.6                    | ED3     | 44.1             | 20.4              | 0.2                   |

![Figure 8. The Block diagram of CAN message transmitting cycle.](image-url)
Table 2. The test result of the temperature and humidity data acquisition system with temperature 30 °C and relative humidity 60%RH

| Test  | humidity %RH | temperature °C | relative error (%) |
|-------|--------------|----------------|-------------------|
| ED1   | 64.1         | 30.4           | -0.3              |
| ED2   | 63.9         | 30.6           | 0.4               |
| ED3   | 64.6         | 30.1           | 0.6               |
|       | Honeywell humidity probe |   |   |
|       | 64.4         | 30.7           | -0.3              |
|       | 63.5         | 30.5           | 0.1               |
|       | 64.0         | 30.2           | -0.1              |
|       | infrared thermometer |   |   |
|       | 30.4         | 30.5           | -0.1              |
|       | 30.6         | 30.2           | -0.1              |

It is found that all the maximum relative error of the temperature and humidity is within the design requirement which the maximum permissible error of temperature shall not exceed 0.5%, and the maximum permissible error of humidity shall not exceed 1% after comparing the measurement result acquired by the data acquisition system and the infrared thermometer and the humidity probe.

The experimental result shows that the ED terminal composed of the wireless communication module, MSP430F2274 core CPU and AM2302 composite temperature and humidity sensor can complete the temperature and humidity data acquisition at different locations in the low-speed flue gas wind tunnel and transmit them to the gateway node AP through SimpliciTI wireless network. And the gateway node with dual functions of CAN message and SimpliciTI message transmitting and receiving is working well according to the design scheme.

6. Conclusion

The temperature and humidity data acquisition system based on the CAN/SimpliciTI hybrid network for low-speed flue gas wind tunnel is able to acquire the temperature and humidity data within the measurement accuracy requirements and transmit them to the host computer. The system has the advantage of simple hardware structure and convenient networking. The application of SimpliciTI simplifies the overall wiring of wind tunnel temperature and humidity acquisition systems to the maximum extent. Also, due to the low-power design of the ED terminal, the system can run reliably for a long time, reducing maintenance costs. In addition, the CAN/SimpliciTI hybrid network proposed in this paper also provides new network construction ideas for environmental data acquisition of other large devices or spaces.

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