The Design of Intelligent Sensor Interface Circuit Based on 1451.2

Hua Fan[1], Jiangmin Mao[1], Quanyuan Feng[2], Xu Qi[3], Dagang Li[3], Lang Feng[3], Daqian Hu[3], Xiaopeng Diao[3], Rami Ghannam[4], and Hadi Heidari[4]
[1] School of Electronic Science and Engineering, University of Electronic Science and Technology of China, Chengdu, China
[2] The school of information science and technology, Southwest Jiaotong University, Chengdu, China
[3] Chengdu Sino Microelectronics Technology Co.,Ltd, Chengdu, China
[4] School of Engineering, University of Glasgow, G12 8QQ, Glasgow, UK
Email: fanhua7531@163.com

***Abstract*—At present, there are many complex and diverse bus interface standards in the field of sensor measurement and control, which leads that different sensors unable to be compatible with different field networks, thus increasing the difficulty of data acquisition and processing. In order to improve the compatibility and the intelligent level of sensors, in this work, a novel intelligent sensor interface model defined by IEEE1451.2 standard is proposed. Finally, the self-recognition, plug and play (PNP) functions are verified on FPGA platform.**

***Index Terms*—IEEE 1451, intelligent sensor interface, self-recognition, plug and play, hall sensor**

I. Introduction

At present, different smart sensor networks usually use different bus standards, and there exists many field interface standards, such as CAN, SPI, IIC, and RS485, etc. In this case, ordinary sensor interfaces are not versatile, leads that extension and transplantation between different field buses and network are difficult. For example, if the user or developer needs to replace the sensor on the circuit board with a higher performance one, but the communication standards and pin structures of the new and old sensor could not be the same, it will be hard to replace the old one. In order to figure out this problem, IEEE 1451 standard is formulated to standardize and universalize smart sensor interfaces in the late 1990s by the National Institute of Standards and Technology (NIST) and the International Institute of Electrical and Electronics Engineers (IEEE), they co-organized a seminar on the development of smart sensor interfaces and promoted general network standards for sensor connectivity, and ultimately came up with a universalize sensor interface standard []. The emergence of the IEEE 1451 unifies the standard of the sensor interface and can realize plug and play (PNP). It solves the compatibility problems faced by different manufacturers' sensors when accessing different fieldbuses and networks. It also brings convenience to the integration and maintenance of the system. With the support of IEEE 1451 standard, even if with different ADCs, microprocessors and network protocols transceivers, the sensor system can still be used with only a few changes, which can greatly reduce the cost of development and usage. The plug and play function makes it easy for users to replace, increase or decrease smart sensors in the network. The standard only defines the rules for the interface, while both Bluetooth or ZigBee have the Protocol stack and code [1]–[3].

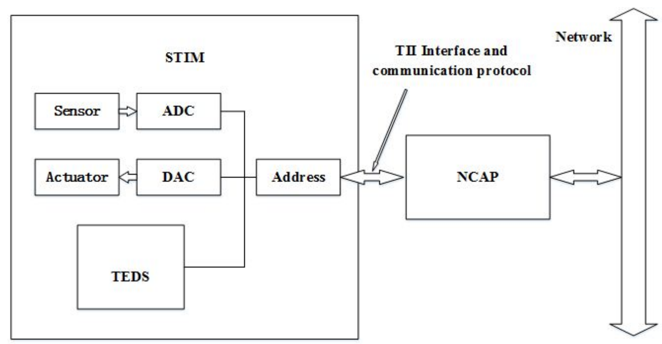

Fig. 1. Functional framework of IEEE 1451.2 interface standard

In order to improve the adaptability and compatibility of the sensor, this work mainly focus on the sub-standards of IEEE 1451.2, we designed an intelligent sensor interface circuit implemented on FPGA, which provides a convenience for integration. The main parts of this system include smart sensor module, Smart Transducer Interface Module (STIM), network adapter processor, and Network Capable Application Processor (NCAP). STIM relates to the design of the sensor independent interface Transducer Independent Interface (TII) and the sensor electronic data table Transducer Electronic Data Sheet (TEDS) referencing to the IEEE 1451 standard. The interface circuit can realize the self-identification and PNP when connecting the sensor to different fieldbuses and networks interfaces. Finally we built a hardware platform to complete the test and verification of the interface circuit.

A. IEEE 1451.2 standard

The design of the whole smart sensor interface circuit is based on the IEEE 1451.2 standards. The IEEE 1451.2 standard is the Sensor to Microprocessor Communication Protocols using Transducer Electronic Data Sheet (TEDS) Format, which is a 10-line point-to-point digital interface TII between the NCAP, the STIM and the communication protocol between the sensor and the microprocessor, as shown

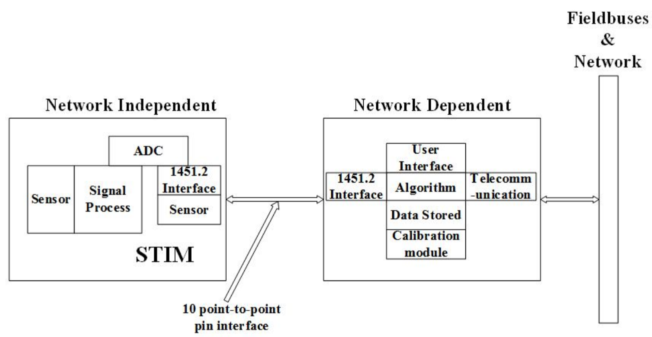

Fig. 2. Concrete implementation model of IEEE 1451.2

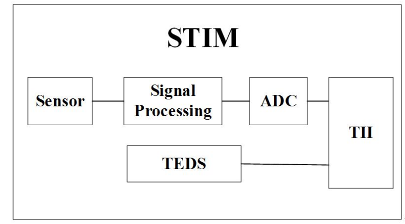

Fig. 3. Structure of STIM

in Fig. 1. This standard enables smart sensor modules with PNP capability, because fieldbuses and network can monitor and configure sensor channels automatically by accessing TEDS. Within this standard, there is no signal processing and signal conversion, so each sensor manufacturer can configure by themselves to maintain the competitiveness in terms of performance and cost [4], [5]. The key feature of IEEE 1451.2 is the digital communication protocol and the self-recognition capability of the sensor, which means the sensor can describe itself to the network, it simplifies the configuration of the automatic system. As shown in Fig. 2, the structure of the smart sensor is divided into two modules. The first module STIM includes sensors and TEDS, and the second module NCAP includes network protocols and application software. The former mainly considers the interface between the underlying sensor and actuator, which mainly stores attributes such as manufacturer, production date, physical unit, data model, calibration model, trigger, and parameters, it can implement calibration for various sensors; the latter is mainly for a variety of networks, including fieldbus and the network protocols, which is connected with the smart sensor module through a standard interface to complete the physical connection and data exchange.

TEDS stores data such as sensor scale parameters, calibration, and vendor information in a digital manner, making it unnecessary to record sensor data sheets on paper, simplify sensor configuration, and eliminate the possibility of errors occurrence. TEDS not only provides the self-identification capability of the sensor, but also be able to automatic calibration. The TII is a 10-wire interface connecting NCAP and STIM. This interface has nothing to do with the sensor type, the fieldbuses and network. It mainly defines the point-to-point connection between NCAP and STIM. The sensor independent interface TII has the following characteristics [6]:

(1) Trigger function, triggering sensor to read/write;

(2) Data transmission is based on the Serial Peripheral Interface (SPI) protocol, and plus several dedicated lines to provide power, ground and special-purpose control lines.

(3) Writing byte data transfer protocol (from NCAP to STIM);

(4) Reading byte data transfer protocol (from STIM to NCAP);

The standard also defines a generic object model that describes smart sensors network and defines a flexible modular set, which includes network interface, measurement, control functions and sensor interfaces, all of which are implemented through NCAP. Therefore, any sensor may, theoretically, be connected to any network as long as it has a suitable NCAP. NCAP is used to read the data sent from the STIM interface, convert it to the bus transmission format, and then send it out through the bus controller. When the remote terminal wants to operate the lower layer actuators through the bus, NCAP accepts the data from the bus, de-composes it into its own data format, and then passes it to the STIM interface to complete the control of the lower executor. Different bus formats have different data transmission format, but as long as there is a code library in the NCAP control program, this part of the program does not need to be modified when changes the bus . NCAP acts as a bridge among the STIM, the fieldbuses and networks. The functions of NCAP mainly include:

(1) Control the STIM and accept the data transmitted by the STIM;

(2) Smoothly connect data to different field networks;

(3) Read the data of sensor and TEDS.

B. Research and Design of Smart Sensor Interface Module STIM

Based on the STIM model described in IEEE 1451.2, the STIM module consists of a sensor interface module, an electronic data sheet TEDS, and a sensor independent interface TII, as shown in Fig. 3. When the STIM module is running, the sensor signal inputs to the A/D conversion and converts into a digital signal, and then the data is transmitted to the NCAP through the TII. At the same time, NCAP read the data stored in the TEDS of the STIM module to realize the functions of sensor self-identification. The TII is a 10-line point-to-point digital interface defined in IEEE 1451.2 standard to achieve data transmission between STIM and NCAP, as shown in Fig. 4. Fig. 5 shows the structure of transmission protocol between NCAP and STIM. The read/write structure in Fig. 5 is byte transmission. The TII interface stipulates the way of trigger, method of bits transmission, protocol of Read/Write. The triggering process typically occurs before reading data or after writing to the actuator. NCAP acts as the trigger source and the STIM module serves as the response source. The specific implementation process is that in the NCAP waiting time for writing channel, NCAP sends a trigger signal to the STIM module through the NTRIG line, the STIM module sends a trigger response signal through the NACK line after receiving the trigger signal, sends a trigger response signal through the NACK line, then the NCAP idles the NTRIG line and the STIM idles the NACK line to completes the trigger function.

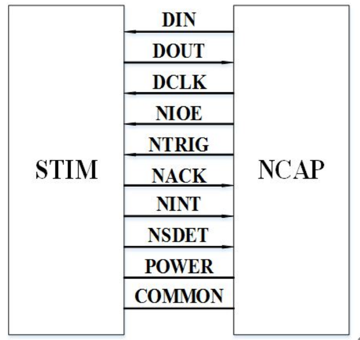

Fig. 4. Structure of TII

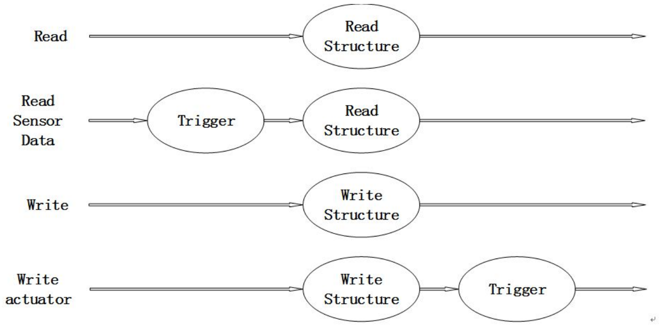

Fig. 5. TII Communication protocol

Data is transmitted between the STIM and the NCAP through the DOUT line with bit form and the entire transmission process is controlled by the clock line DCLK. The transmission process is shown in Fig. 6: on the first negative edge of DCLK, the first byte is transmitted by the STIM and received by the NCAP when DCLK is high. On the subsequent positive edge of DCLK, the byte data will be latched by NCAP, the following bit transmission repeats the above steps. Reference to the IEEE 1451.2 standard, NCAP can ignore the state of the DOUT line when data is transferred from the NCAP to the STIM; also the STIM module can ignore the state of the DIN line when data is transferred from the STIM to the NCAP. In other words, the DIN and DOUT lines here are in a half-duplex communication state.

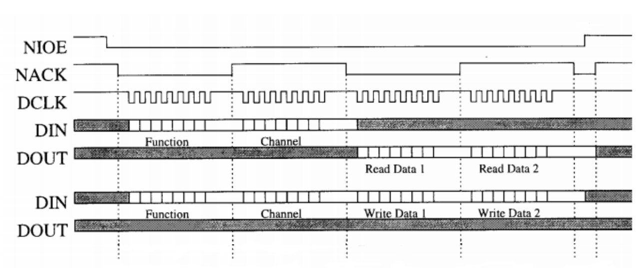

Fig. 6. Timing about transmission of even-number data

In this work, the whole TII interface program is simulated, the simulation result is shown in Fig. 7, in which the timing diagram matches well with the TII interface timing in Fig. 8 defined by IEEE1451.2, and the response signal NACK is flipped after every 8-bit data transmission.

This subject uses FPGA to realize ROM to store the data

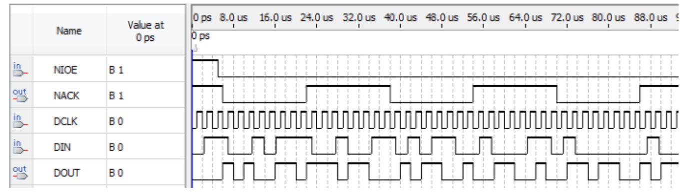

Fig. 7. The simulation result of TII timing for reading and writing data

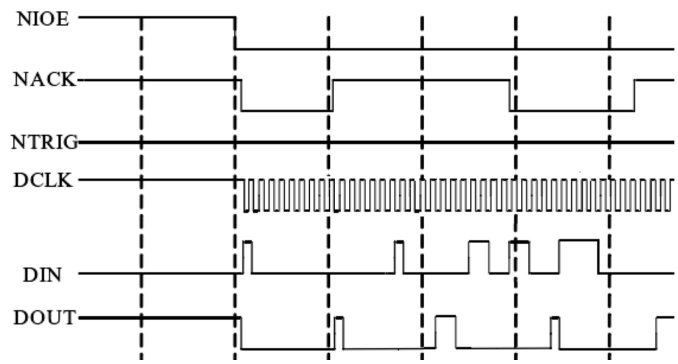

Fig. 8. Standard for TII reading and writing data defined by IEEE 1451.2

information in Meta-TEDS, Channel-TEDS and User-TEDS. It is read by NCAP through TII interface to realize sensor self-identification and plug-and-play. The Verilog code of the ROM module part and initial file is shown in Fig. 9, respectively. The initial file is shown in Fig. 10.

```
altsyncram_component.address_aclr_a = "NONE",
altsyncram_component.clock_enable_input_a = "BYPASS",
altsyncram_component.clock_enable_output_a = "BYPASS",
altsyncram_component.init_file = "TEDS_ROM.mif",
altsyncram_component.intended_device_family = "Cyclone IV E",
altsyncram_component.lpm_hint = "ENABLE_RUNTIME_MOD=NO",
altsyncram_component.lpm_type = "altsyncram",
altsyncram_component.numwords_a = 256,
altsyncram_component.operation_mode = "ROM",
altsyncram_component.outdata_aclr_a = "NONE",
altsyncram_component.outdata_reg_a = "UNREGISTERED",
altsyncram_component.widthad_a = 8,
altsyncram_component.width_a = 8,
altsyncram_component.width_byteena_a = 1;
```

Fig. 9. The Verilog codes of TEDS

C. Testing and Verification of Smart Sensor Interface Circuits

After completing the design of the STIM module and the NCAP module, the combination of STIM and NCAP module can be Intelligent sensor interface circuit as descripted in the IEEE1451.2 standards. We have tested the combination module to verify the function of TII interface transmission, TEDS data and data access to the different field networking through the NCAP, the platform is shown in Fig. 11, and the data display result is shown in Fig. 12.

We must test if the sensor is able to access different field networks via the NCAP, then it is necessary to simulate the field with different bus interfaces. The NCAP has four interfaces for the experiment: UART, SPI, CAN, and RS485, it is just needed to build a network site with these four interfaces. For the UART network site, the computer serial port software XCOM is used for simulation. The software

TEDS_ROM.mif

Addr	+0	+1	+2	+3	+4	+5	+6	+7
0	00000000	00000000	00000000	01001010	00000010	00000001	10001101	01111011
8	10000101	01101110	00000011	00111101	11111000	10100000	01110011	10110100
16	00000000	00000000	00000000	00000001	00000001	00000010	00000000	00000001
24	00000000	00000000	00000000	00000000	00111011	00000011	00010010	01101111
32	00111010	10000011	00010010	01101111	00111010	10000011	00010010	01101111
40	00111101	01110101	11000010	10001111	00111101	01111010	11000010	10001111
48	00111010	10000011	00010010	01101111	00111011	01000100	10011011	10100110
56	00111011	10000011	00010010	01101111	00111100	11110101	11000010	10001111
64	00111100	11110101	11000010	10001111	00000000	00000001	10000110	10100000
72	11111000	00000000	00000000	00000000	00000000	00000000	00000000	00000000
80	00000000	00000000	00000000	00000000	00000000	00000000	00000000	00000000

Fig. 10. initial file mif

Fig. 12. Screen displays:“ the output of sensor is 2.091504V, the value for the measurement is 4.921640 mT”.

can realize serial port communication and display the received data, which can verify the function of NCAP accessing UART network. For SPI, CAN and RS485 interfaces, STM32ZET6 is also used as the main control chip to simulate the field network with these three interfaces. During the measurement, TFTLCD liquid crystal displays the collected sensor data and TEDS information, ss shown in Fig. 12. The control chip used for the liquid crystal is display ILI9341. The STIM and the NCAP are connected through the independent sensor interface TII, and then are connected to different field networks through the network adaptation processor NCAP. As a result, the screen displays:“ the output of sensor is 2.091504V, the value for the measurement is 4.921640 mT” in Fig. 12. The measurement results show that the NCAP can successfully transmit the sensor data in the STIM module and the data in the sensor electronic data table TEDS to the field network with the CAN, RS485 SPI interface. It shows that the sensor data in the STIM module and the information in the sensor electronic data table can be passed to the NCAP through the TII and be connected to different field networks through the NCAP. This enables the PNP functionality of the sensor.

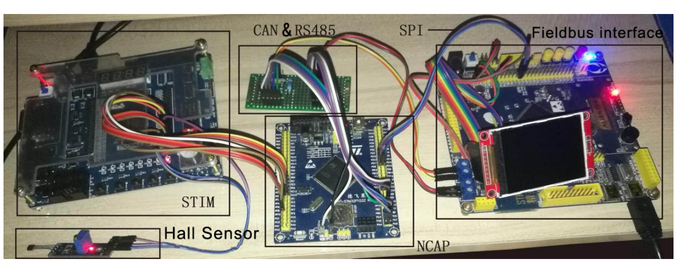

Fig. 11. The whole hardware platform

II. Summary

This work has carried on research and analysis on IEEE 1451 standard, especially on IEEE1451.2 standards, and we have designed an intelligent sensor interface circuit based on this standard. Using FPGA, the sensor independent interface TII, the sensor electronic data table TEDS and the sensor interface module STIM were completed, and the network adapter processor NCAP was designed based on STM32ZET6. Finally, the function of the smart sensor interface circuit is verified through hardware testing, which demonstrates the sensor data and the information in the sensor electronic data table TEDS can be accessed to the field network via the network adaptation processor NCAP, furthermore, PNP and self-identification are realized.

Acknowledgment

The work of Hua Fan was supported by the National Natural Science Foundation of China (NSFC) under Grant 61771111, supported by Sichuan Provincial Science and Technology Important Projects under Grant 19ZDYF2863, as well as supported by China Postdoctoral Science Foundation under grant 2017M612940 & 2019T120834 and Special Foundation of Sichuan Provincial Postdoctoral Science Foundation.

The work of Quanyuan Feng was supported by the National Natural Science Foundation of China (NSFC) under Grant 61531016, supported by Sichuan Provincial Science and Technology Important Projects under Grant 2018GZ0139, 2018ZDZX0148 and 2018GZDZX0001.

References

[1] H. Fan, J. Yang, F. Maloberti, Q. Feng, D. Li, D. Hu, Y. Cen, and H. Heidari, “High Linearity SAR ADC for High Performance Sensor System,” in *2018 IEEE International Symposium on Circuits and Systems (ISCAS),*. IEEE, 2018, pp. 1–4.

[2] N. Kularatna and B. Sudantha, “An environmental air pollution monitoring system based on the IEEE 1451 standard for low cost requirements,” *IEEE Sensors Journal*, vol. 8, no. 4, pp. 415–422, 2008.

[3] A. Kumar, V. Srivastava, M. K. Singh, and G. P. Hancke, “Current status of the IEEE 1451 standard-based sensor applications,” *IEEE Sensors Journal*, vol. 15, no. 5, pp. 2505–2513, 2015.

[4] L. Guo, J. Wu, Z. Xia, and J. Li, “Proposed security mechanism for XMPP-based communications of ISO/IEC/IEEE 21451 sensor networks,” *IEEE Sensors Journal*, vol. 15, no. 5, pp. 2577–2586, 2015.

[5] D. S. Gangwar and S. Tyagi, “Challenges and Opportunities for Sensor and Actuator Networks in Indian Agriculture,” in *2016 8th International Conference on Computational Intelligence and Communication Networks (CICN)*. IEEE, 2016, pp. 38–42.

[6] G. Wu and S. Chen, “Design of Wireless Smart Sensor Module for Infant Incubator Test,” in *2016 5th International Conference on Measurement, Instrumentation and Automation (ICMIA 2016)*. Atlantis Press, 2016.