International Journal of Hybrid Information Technology
Vol. 7, No. 6 (2014), pp. 101-114
http://dx.doi.org/10.14257/ijhit.2014.7.6.08

Design and Implementation of Self-validating Pneumatic Actuator Hardware System Based on DSP and MCU

Zhigang Feng and Meng Qiu

School of Automation, Shenyang Aerospace University, Shenyang, Liaoning, China
fzg1023@yeah.net

Abstract

Self-validating (SEVA) pneumatic actuator is a new generation of actuator which can not only give the corresponding output according to the input control variable but also give the accuracy of the control output and status of the actuator itself and other information. A dual processor system is implemented using C8051F060 and TMS320F28335 to acquire the signals and complete fault detection, diagnosis and self-validating parameters calculating. C8051F060 is used to data acquisition and preprocessing of the actuator inner signals, and communicate with Host PC.TMS320F28335 is used to run the self-validation algorithm and fault diagnosis algorithm and transfer the self-validation outputs to C8051F060. Experimental results indicate that the sell-validating *unit can acquire the actuator inner sensors data correctly in normal state and fault state. With software modification of DSP and MCU, the system can be used in data acquisition and signal processing for other actuators.*

Keywords: *Self-validating (SEVA) pneumatic actuator; fault diagnosis; actuator status; MCU; DSP*

1. Introduction

In 1999, researchers from Department of Engineering Science, Oxford University, proposed the concept of Self-validating actuator [1], which was based on the self-validating sensor technology [2, 3]. Compared with conventional actuator, Self-validating actuator is a new generation of actuator, which can not only give the corresponding output according to the input control variable but also can implement self fault detection and diagnosis, and give the accuracy of the control output and status of the actuator itself and other information. It will become an important development direction of actuator.

The self-validating actuator model, which was proposed by Professor Clarke of Oxford University, only gave the output parameters of the model and their significance but not the internal function model of the self-validating actuator. In this paper, a self-validating actuator based on Clarke's model is proposed, as shown in Figure 1.

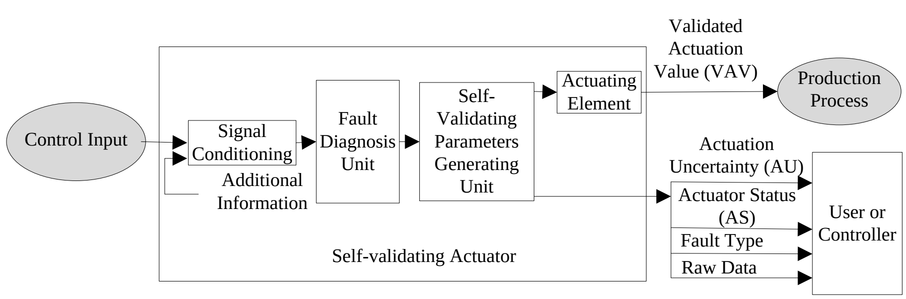


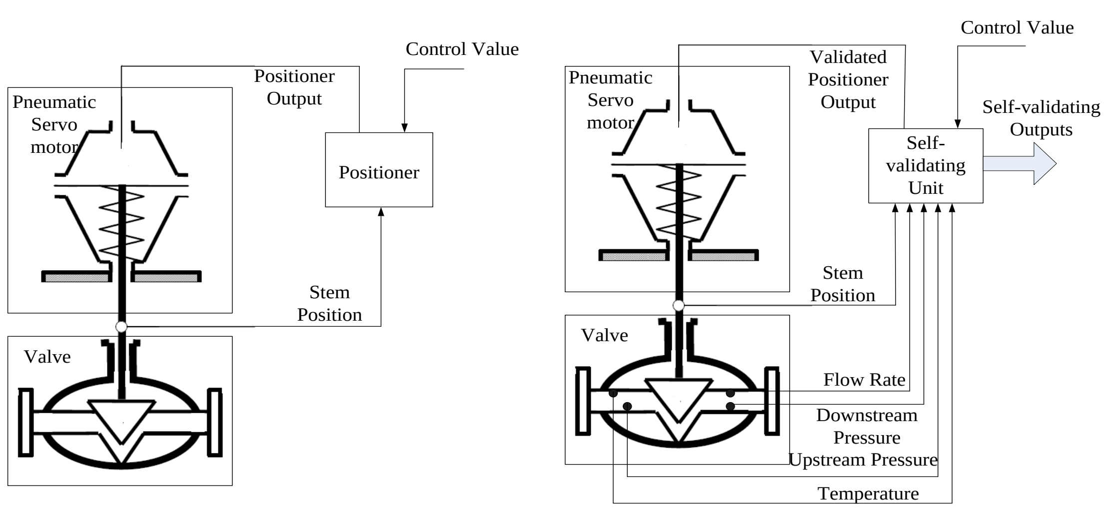
Figure 1. Self-validating Actuator Function Model

ISSN: 1738-9968 IJHIT

Through adding fault diagnosis unit and self-validating parameters generating unit, Self-validating actuator not only gives the implementation of actuator self-inspection and self-diagnosis, but also gives the control output reliability and some other indexes, such as Validated Actuation Value (AU), Actuation uncertainty (AU), Actuator Status (AS), Fault Type and Raw Data etc. In order to implement the self-validating functions, the self-validating actuator integrates amounts of sensors and high performance microprocessor in the conventional actuator. It can get the actuator inner information effectively, which provides the firm basis for self fault detection, diagnosis and self-validating parameters calculation of self-validating actuator. Self-validating actuator can not only provide control output confirmation, but also provide the control output uncertainty, actuator status, the fault type , all the original data (such as the adding measurement of the sensors) and other parameters. By this way, user or controller can real-time understand the status of the actuator, and according to the various self-validating information to take reasonable operation which greatly improve the reliability of the control system.

In order to realize the pneumatic control valve fault self-detection and self-diagnosis, the dynamic and structural characteristic of the regulating valve is studied; the impact of the various fault modes of the regulating valve is analyzed. Based on these, some sensors are integrated in the regulating valve to get more information for self-validating functions implementation. In this paper, a self-validating pneumatic actuator based on three component pneumatic valve is developed, which had been added the temperature, flow rate and pressure sensors that was used to measure temperature, flow, input and output pressure of the valve on the body position. All of these measures provide redundant information for the condition monitoring of the self-validating valve.

Figure 2 shows the Traditional and self-validating pneumatic actuator structure diagram. The traditional pneumatic actuator [4] consists of three parts: pneumatic servo motor, positioner and control valve, as shown in Figure 2 (a). The self-validating pneumatic actuator, as shown in Figure 2 (b), also consists of three parts: pneumatic servo motor, self-validating unit and control valve. There are one temperature sensor, two pressure sensor and one flow rate sensor are integrated in the valve. The self-validating unit acquires the stem position, flow rate, upstream pressure, down stream pressure and temperature and control value to implement all self-validating functions and give self-validating outputs.



(a) Traditional Pneumatic Actuator Structure (b) Self-validating Pneumatic Actuator Structure

Figure 2. Traditional and Self-validating Pneumatic Actuator Structure Diagram

In this paper, the hardware and software design and implementation of the Self-validating Unit are described in detail. Section 2 gives the overall architecture of the system. Section 3 introduces the hardware system design and implementation detailed. Section 4 introduces the software design and implementation in detail. Section 5 gives the experiment and results.

2. Overall Design of the System

The Self-validating Unit acquires all the sensors data inner the self-validating actuator, and implement fault self-detection, self-diagnosis and calculates all the self-validating parameters of the actuator.

The hardware system structure of the Self-validating Unit, shown in Figure 3, consists mainly of signal conditioning circuit (including the signal amplification circuit, filter circuit, ADC input buffer circuit *etc.*,) and signal acquisition and processing circuit (digital signal processing unit of DSP28335 and data acquisition circuit of C8051F060 etc.). The two mainly part was integrated in one PCB.

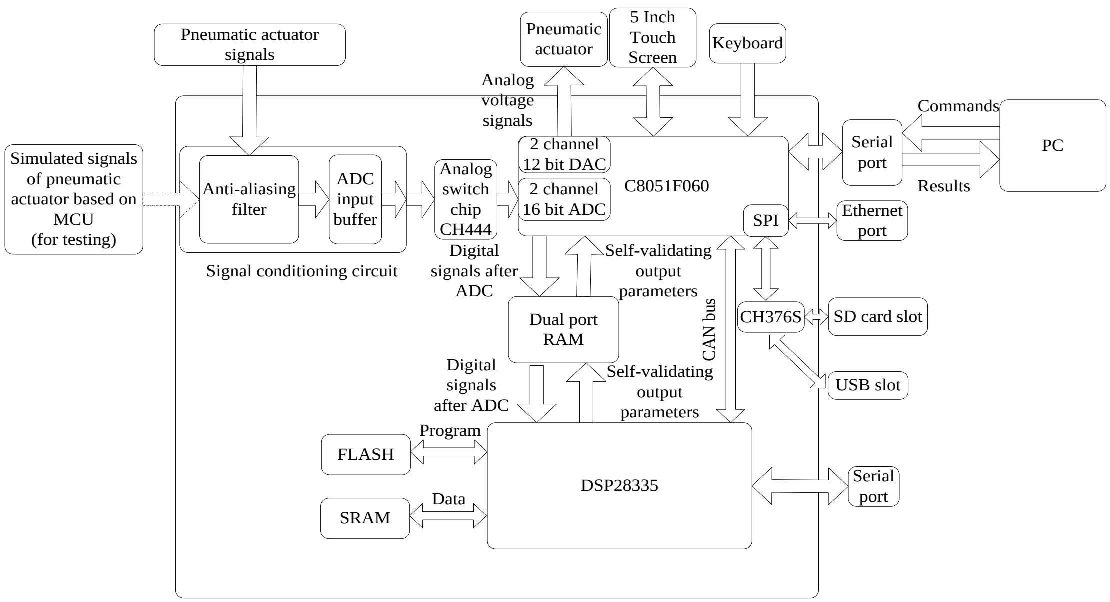


Figure 3. Schematic Architecture of the Double Processor System for Self-validating Actuator

Signal conditioning circuit mainly realizes the following functions, signal amplification and filtering of the sensors data inner the actuator, input data buffer for analog to digital conversion. ADC of C8051F060 can realize 16-bit two synchronous sampling, then the MCU storages the sampling data into the dual-port RAM, so that DSP28335 would use these data for processing self-validating algorithms.

The core of the signal processing circuit is DSP28335. F060 (C8051F060 [5-7], hereinafter the same) storages a set of ADC data into the dual-port RAM. After delivering the start processing command to the DSP28335 through the CAN bus, DSP28335 would access the data from the dual-port RAM for data processing and send the data processing results through the CAN bus to the F060, then F060 will output the data to PC using serial port, USB port or Ethernet port. Besides, the hardware was integrated with the CH376 file management control chip which was used for MCU to read and write U disk or SD card file.

3. Hardware Design of the System

The following will introduce the analog filter circuit, ADC input buffer circuit, C8051F060 circuit and the design of DSP data processing circuit respectively in detail.

3.1. Analog Filter Design

The system uses two order voltage controlled voltage source (VCVS) filter for analog input filter [8]. It has the advantages of good frequency selectivity, simple design, and flexible adjustment of the filter parameters, stable performance and limited gain. Figure 4 is a schematic diagram of the VCVS filter. The OP213 filter chip was selected because of the characteristics of low noise, low drift and high precision. The filter quality factor Q and cutoff frequency f can be easily changed by adjusting peripheral resistance and capacitance values, which will realize the filter of different types. In order to ensure the better frequency selectivity and smaller distortion, here the Butterworth filter is chose which has cutoff frequency of 501.3Hz and quality factor of 0.496.

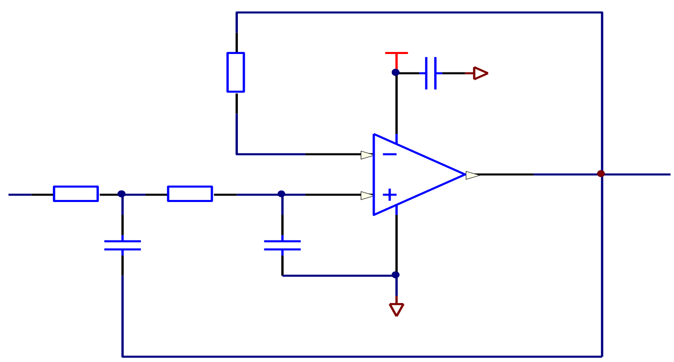


Figure. 4. Voltage Controlled Voltage Source Low-pass Filter Schematic

3.2. AD Input Buffer Circuit Design

In the process of signal acquisition, AD holding capacitor connected with the conditioning circuit output will make the disturbance of output. In order to ensure the sampling accuracy of 16-bit AD, the final circuit connected to the AD must be able to guarantee the output signal rapidly stabilized at the sampling time. In order to make the jitter smaller when compared with the 16-bit AD signal resolution, the AD input buffer circuit was designed shown as in Figure 5.

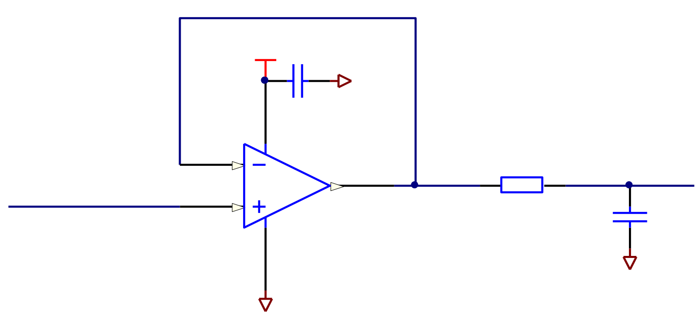


Figure 5. The AD Input Buffer Circuit Schematic

The video operational amplifier AD8052, which has character of low noise, low distortion and wide band, has the amplifier unit gain bandwidth of typical value 110MHz and the output voltage slew rate 145V/us. The signal stability to a precision of 0.1% time of this amplifier is 50 ns, so it can be used as load under the condition of fast and stable signal capacitance retention samples to AD.

3.3. AD Acquisition Circuit Design

Because the C8051F060 microcontroller has only two 16-bit synchronous sampling channels, the single pole four throw low resistive analog switch chip CH-444G which could acquire 2-way signals of the eight signal at the same time should use 4 times to acquire all the 8 way signals. The circuit connection schematic was shown in Figure 6.

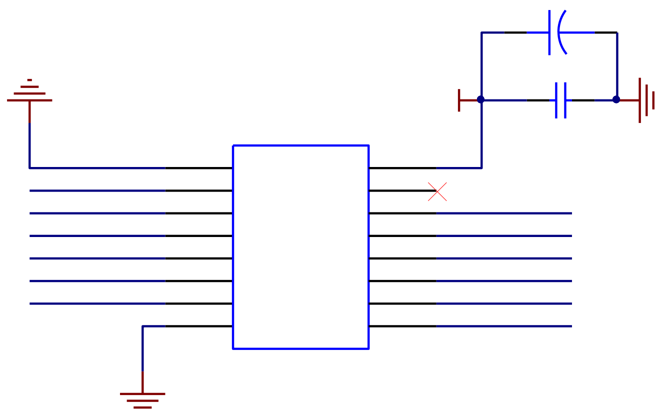


Figure 6. Analog Switch Circuit Connection Schematic

The CH-444G has the characteristics of low resistance (typically 5 ohms), high bandwidth (BW = 570MHz), fast switching (Ton/Toff < 5nS), which could fully meets the system requirements. In addition, two-way switch choice signals were given by the standard I/O output of MCU. The gate outputs were sent to the two 16-bit analog-to-digital unit of MCU. When data conversion completed by C8051F060, the data will be written to the dual-port RAM, at the same time, a message was sent to DSP28335 through the CAN bus to notify it to read data from the dual-port RAM.

3.4. Ethernet Interface Circuit Design

The hardware structure of the expansion of the network port is shown in Figure 7. Compared with network communication, RS232 and RS485 have the following problems during data transmission [9]:

(1) Data transmission efficiency is low (at least loss of 20% data), especially in the massive data transmission;

(2) Data transfer rate is relatively low, and even the maximum transmission baud rate was used, the maximum baud rate that computer generated is about 128000bit/s, equivalent to 0.128Mb/s, and this rate is relative low compared with the rate of Ethernet of 100Mb/s;

(3) The communication distance of the serial communication mostly cannot exceed 200 meters, and when usually multiple sampling cannot guarantee the communication distance between equipment is in this range. However, Ethernet transmission distance through the

network communication equipment can reach farther (much farther than the serial communication distance) and can realize the remote control. Future the Ethernet export can expand the communication mode between the Host PC control software and slave machine. Compared with RS232 and RS485, there is a deep leap for the quality in data transmission of Ethernet port.

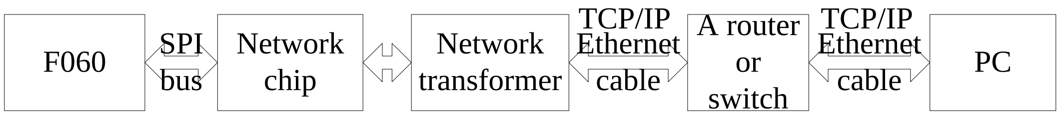


Figure 7. Ethernet Communication Structure Graph between PC and Slave-Computer

In this paper, W5200 chip is used to implement Ethernet communication for the self-validating unit. The W5200 chip is a Hardwired TCP/IP embedded Ethernet controller that enables easier internet connection for embedded systems using SPI (Serial Peripheral Interface). Through using W5200, TCP/IP Stack, 10/100 Ethernet MAC and PHY are implemented using a single chip. Figure 8 shows the interface circuit of W5200 with F060, including the clock circuit, power supply circuit, reset circuit and SPI interface circuit.

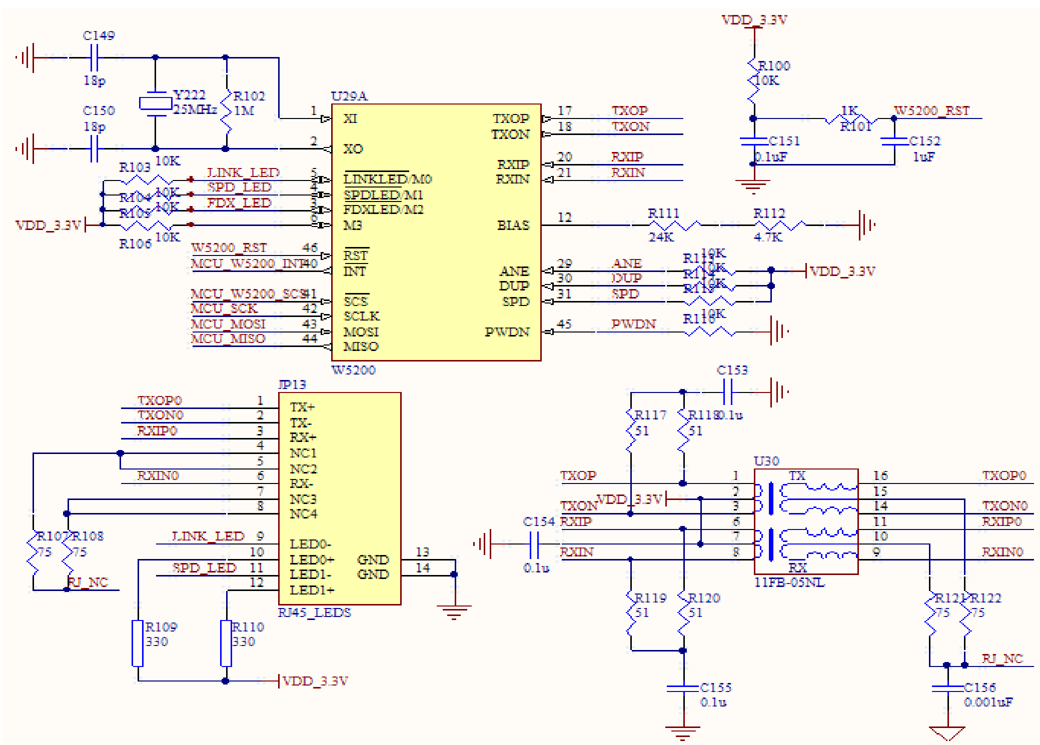


Figure 8. Interface Circuit of W5200 with F060

3.5. File Access Circuit Design

The system which was integrated with CH376 access circuit would mainly use for storing the results of fault diagnosis when it was needed in the future [10]. CH376 supports USB device mode and USB host mode, in addition, it also has built-in USB communication protocol basic firmware, built-in firmware processing Mass-Storage mass storage device dedicated protocol, built-in SD card communication interface firmware, built-in FAT16, FAT32 and FAT12 file system management firmware. And the chip also supports common USB storage devices and SD cards. The application diagram of CH376 chip in this system was shown in Figure 9.

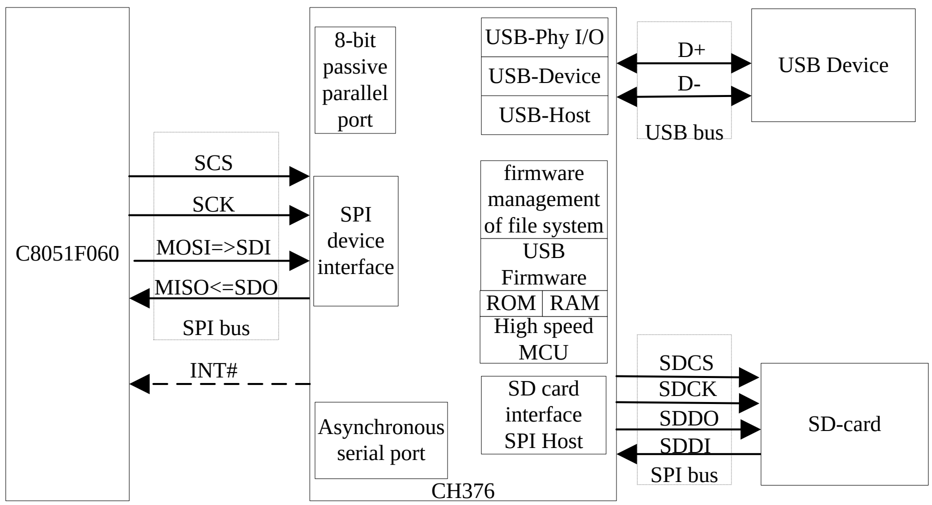


Figure. 9. CH376 Access Circuit Schematic

3.6. C8051F060 and TMS320F28335 Data Processing Circuit Design

The C8051F060 microcontroller, which was used as interface and controller, take charge of the analog to digital conversion, data access, data input and output and communicate with the host computer, etc. Using single chip microcontroller as the interface circuit is because the MCU has 2 channels of 16 bit AD converter, DMA access, CAN bus, serial port and SPI bus hardware interface internally resources which is able to fully meet the system requirements and furthermore the MCU is cheap.

Digital signal processing unit consists of F060 and DSP28335 minimum system, a communication interface between the two processor and peripheral control circuit, etc. The minimum system F060 and DSP28335 contains the power, clock, reset circuit, JTAG interface and the memory expansion. F060 extended the 4K x 16 dual-port RAM which was used for storing data and processing result buffer after ADC through DMA hardware. Besides, F060 communicated with PC through SCI interface. DSP28335 extended 256K × 16 Flash which was used to store program.

The CAN bus which was used for communicating between F060 and DSP28335, was mainly used for transferring the results and processing parameters of the self-validating algorithm. F060 mainly realized analog to digital conversion, storing data to dual-port RAM chip and transferring the results and algorithm parameters through the CAN bus between itself and DSP28335.

Communication between F060, DSP28335 and dual port RAM which would be realized by using the signal of dual-port RAM signs for access was performed as following:

(1) After dual-port RAM semaphore initialization, the dual-port RAM would be divided into 8 parts according to the eight semaphore latches. Signal latches represented corresponding storage space part of dual-port RAM respectively by accessing which we can decide whether it is free.

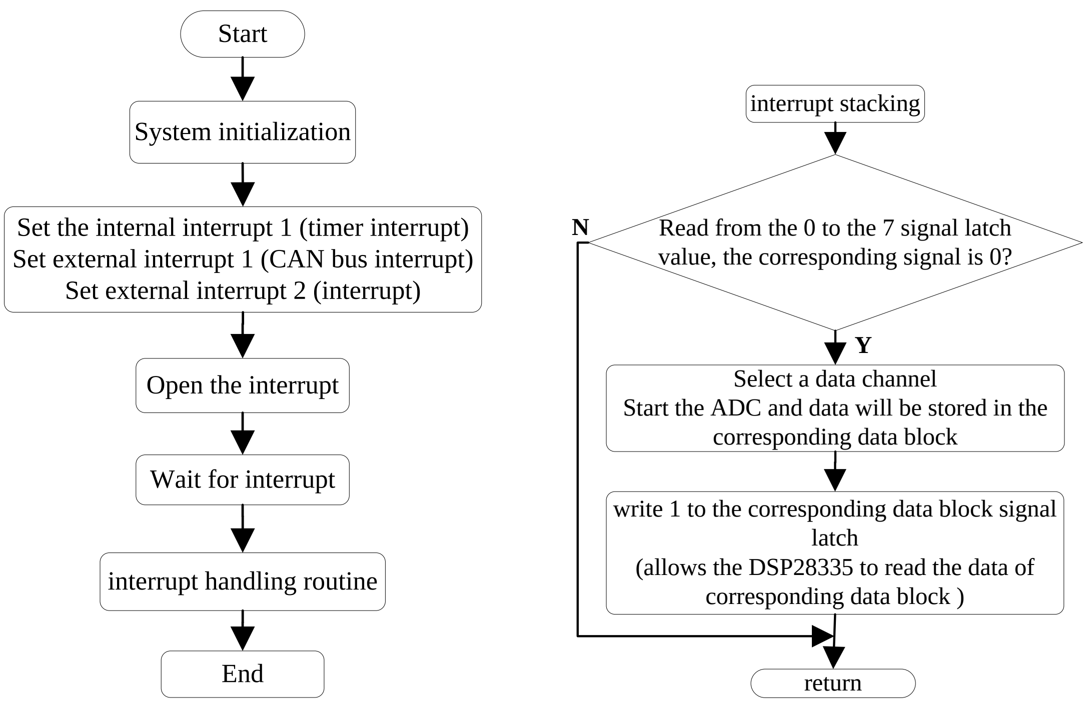
(2) The ADC data of MCU was written to the storage space of dual-port RAM from the first block to the 8th block and set the signal latch to 1 after data being written. Then, DSP28335 read the data by check the signal latch which would confirm whether the data had been written, and set the corresponding signal latch to 0 (by writing 1) which would release the corresponding memory block.

(3) MCU could read the signal latch to determine whether the DSP28335 had read the data, and wrote the new data of ADC. The eight block storage space by cyclic sequence write and read between MCU and DSP28335 that ensure the ADC write of data and processing of data without interruption.

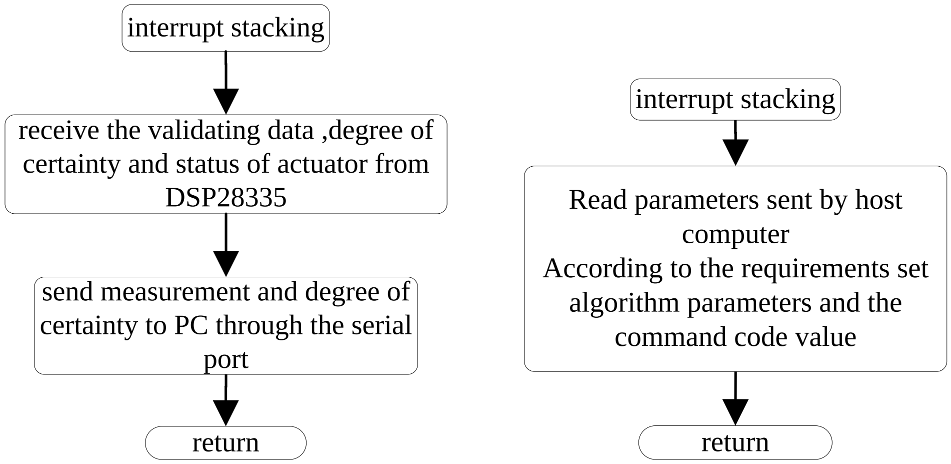
Results of self-validating algorithm were sent to the MCU by DSP through CAN bus, afterwards the results would be sent to PC by microcontroller through the serial port.

4. System Software Design

Taking full account of the hardware design, software of the F060 and DSP28335 were carried out. Software process of C8051F060 was shown in Figure 10. Internal timing conversion interrupt is responsible for choosing the ADC channel, storing data in the dual-port RAM chip and setting the semaphore flags, so that DSP28335 would read data from dual-port RAM according to the semaphore flags. CAN bus data bus interrupt was responsible for receiving self-validation results and pneumatic actuator status which was sent by DSP28335. And then the data would send to the PC through the serial port. The command code and the algorithm parameter would be set by C8051F060 when the serial port interrupt would be responded, and then all of this data would sent to DSP28335 through the CAN bus.

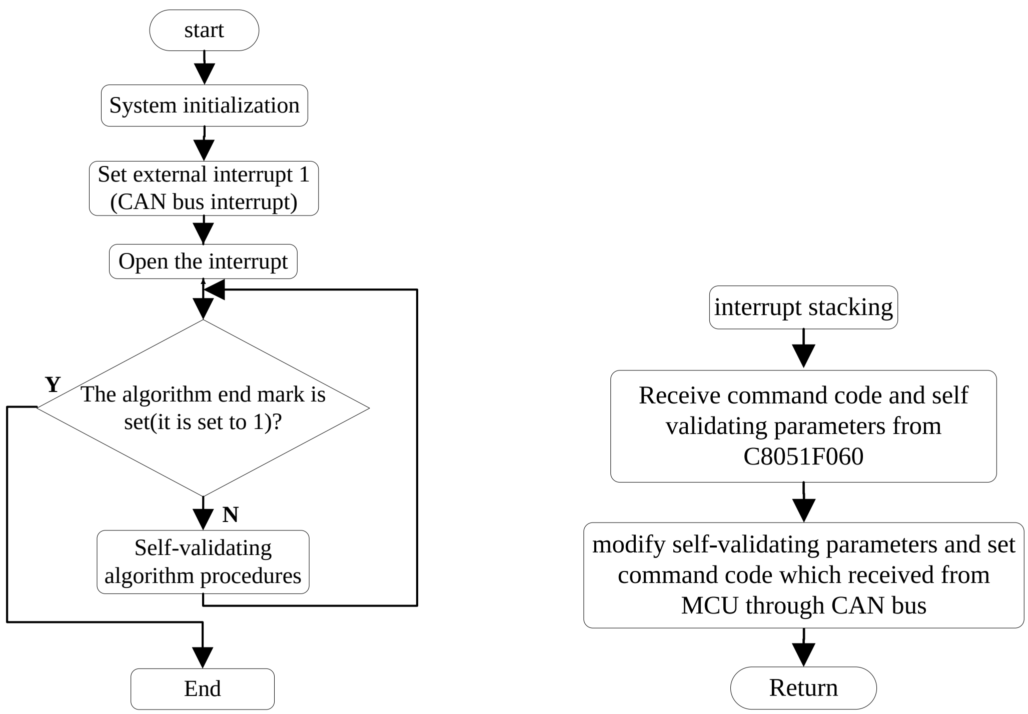


(a) C8051F060 Main Program Flowchart (b) Internal Timing Conversion Interrupt Routine

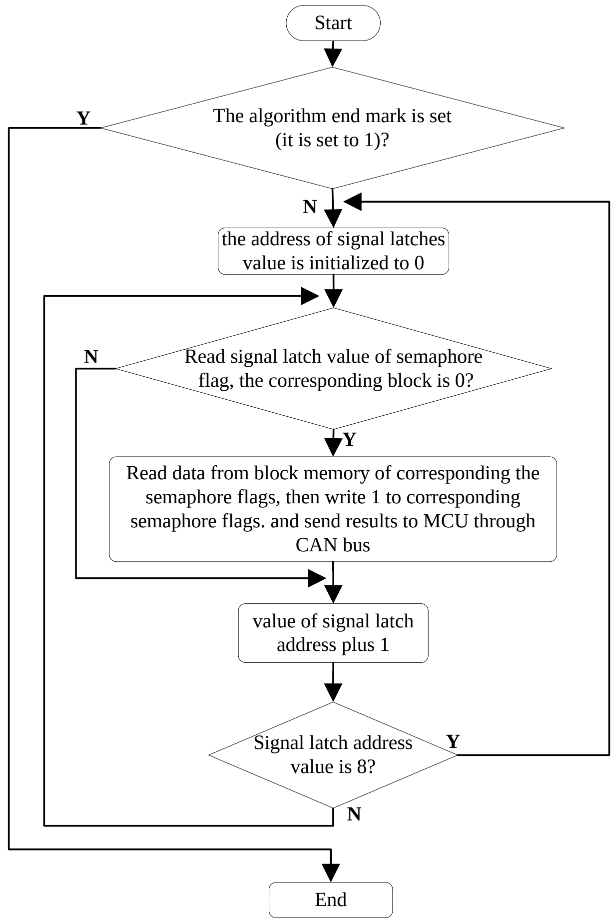


(c) CAN Bus Interrupt Routine (d) SCI Interrupt Routine

Figure 10. C8051F060 Program Flow Chart



(a) DSP28335 Main Program Flowchart (b) Can Bus Interrupt Routine



(c) Dual-port RAM Data Access Flowchart

Figure 11. DSP28335 Software Flow Chart

Figure 11 is the flow chart of DSP28335 software. Self-validating algorithms had been implemented when start command was sent by PC and would decide whether the end of execution stop by judging signal mark of software end. DSP28335 reads the data of dual-port RAM by judging the semaphore flags which was set by the MCU C8051F060 after ADC, and then takes the data for self-validating algorithms. Afterwards, the results of self-validating algorithms would be sent to MCU via the CAN bus. CAN bus interrupt was used for reading the command code and algorithm parameters which was sent by MCU. Then the corresponding execution marks and algorithm parameters would be modified when the parameters were changed.

5. Experiment and Results

Figure 12 shows the photo of the self-validating unit for the self-validating actuator, including power supply circuit, analog filter and AD input buffer circuit, file access circuit, TMS320F28335 circuit, C8051F060 circuit, dual port ARM circuit, W5200 and Ethernet circuit and keyboard interface, LCD interface and serial port interface.

Experiments were done on an advanced process control object system, which has three tanks and a smaller boiler. The self-validating pneumatic valve is installed in the main on the main pipeline, which is used as the primary control device. By giving certain control value, the self-validating pneumatic valve controls the flow rate on the main pipeline. The inner sensors data of the self-validating pneumatic valve including stem position, flow rate, upstream pressure, down stream pressure and temperature are acquired and transmitted to the PC though serial port by the self-validating unit. Figure 13 illustrates the pressure data of 1000 seconds with no valve fault. Figure 14 illustrates the other inner sensors data of 1000 seconds with no valve fault. In which the range of the Control value and Stem position is 0-100%. From these two figures, we can see that, the sell-validating unit acquires the actuator inner sensor data correctly. Figure 15 illustrates the pressure data of 1000 seconds with positioner supply pressure drop fault. Figure 16 illustrates the other inner sensors data of 1000 seconds with positioner supply pressure drop fault.

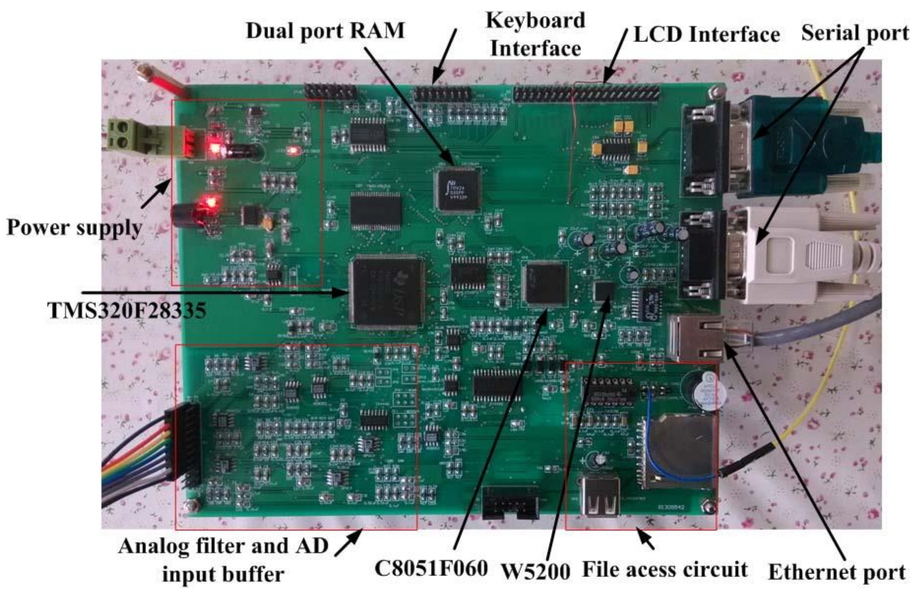


Figure 12. Photo of the Self-validating Unit

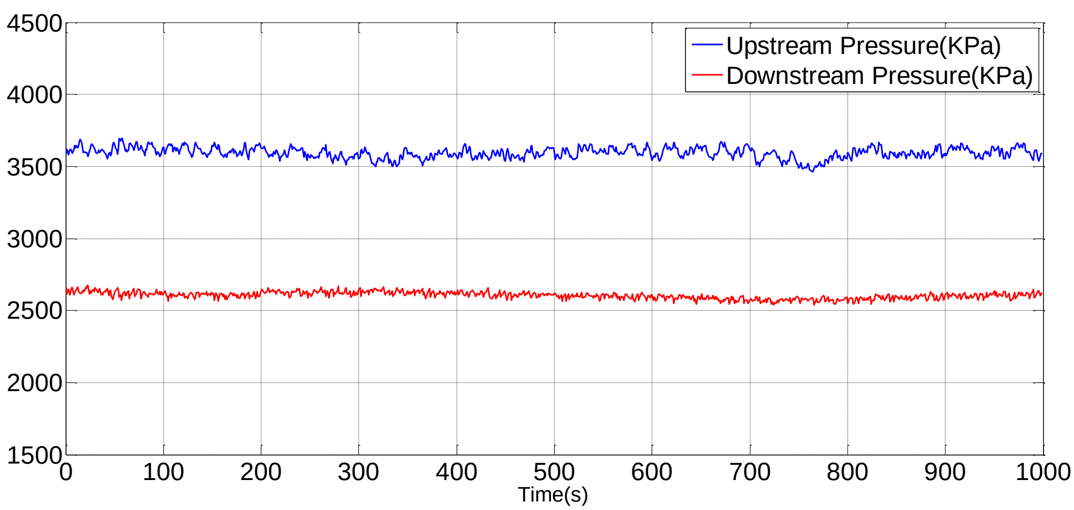


Figure 13. Pressure Data acquired by the Self-validating Unit with 1000 Seconds (without valve fault)

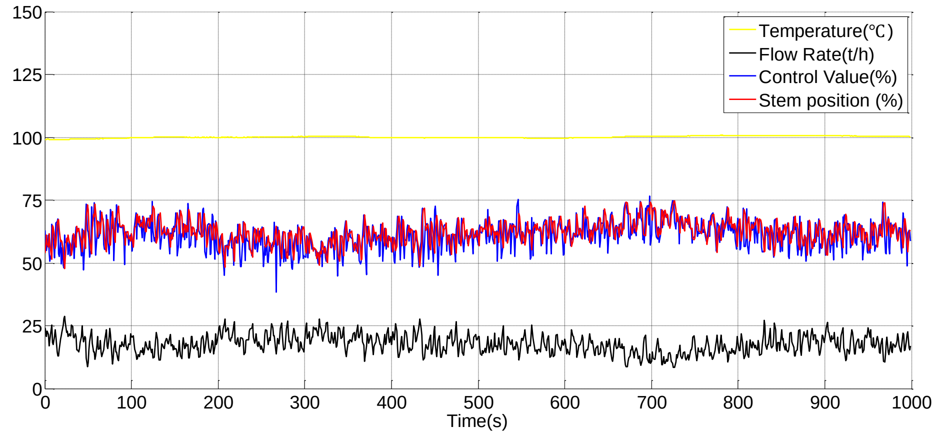


Figure 14. Temperature, Flow, Control value and Stem Position Data acquired by the Self-validating Unit with 1000 seconds (without valve fault)

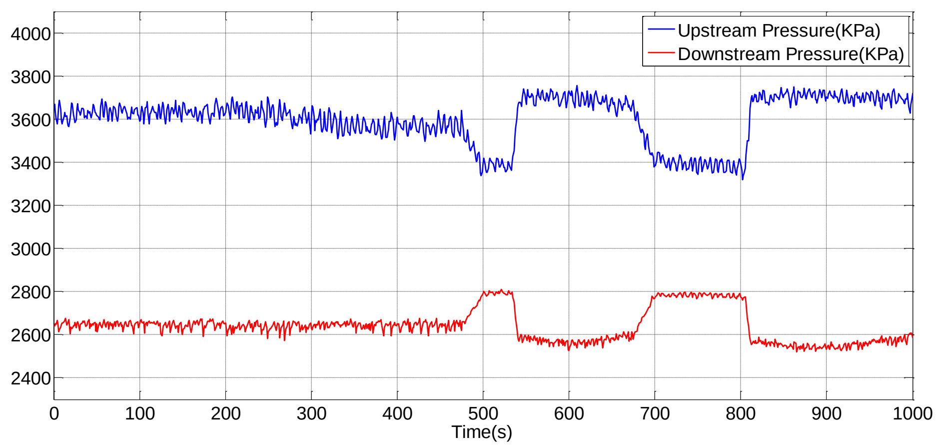


Figure. 15. Pressure Data acquired by the Self-validating Unit with 1000 Seconds (with positioner supply pressure drop fault)

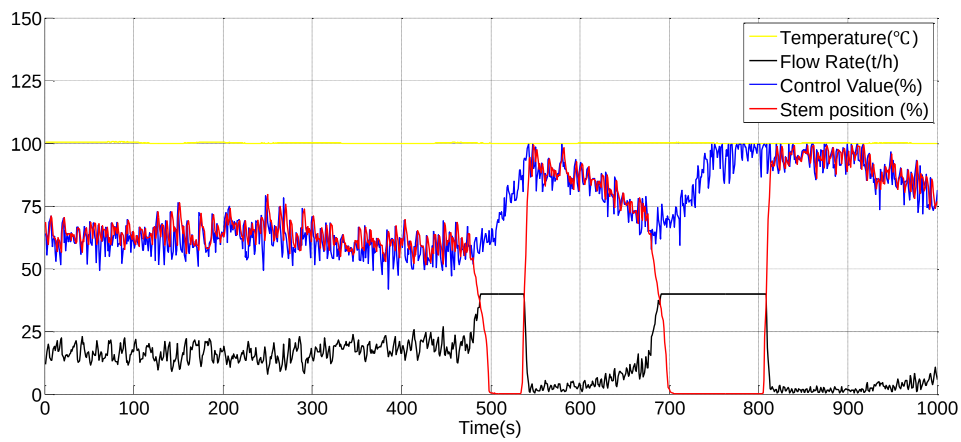


Figure. 16. Temperature, Flow, Control value and Stem Position Data acquired by the Self-validating Unit with 1000 seconds (with positioner supply pressure drop fault)

In these two figure, the supply pressure of the positioner drops under the normal value from about 500 to 540 seconds and 700 to 800 seconds. Because of this, at these tow time span, the stem position drops to 0, the flow rate raises to the maximum value, the upstream pressure drops and the downstream pressure raises. When the supply pressure of the positioner returns to normal, all the actuator inner sensors data are return to normal state. These also verify that the sell-validating unit acquires the actuator inner sensors data correctly.

6. Conclusions

In this paper, a self-validating pneumatic actuator hardware system (Self-validating Unit) based on DSP TMS320F28335 and MCU C8051F060 is described. The hardware design and software design are described in detail. The experiment results show that: the sell-validating unit can acquire the actuator inner sensors data correctly in normal state and fault state. In the future, we will design and implement self-validating algorithms on DSP based on the acquired data, including fault detection and diagnosis method, self-validating parameters calculating methods.

Acknowledgements

The authors would like to thank the financial support of the financial support of the National Natural Science Foundation of China NSFC-61104023.

References

[1] J. Yang and D. W. Clarke, “Self-validating Actuator”, Control Engineering Practice, vol. 7, no. 2, (**1999**) pp. 249-260.
[2] M. P. Henry and D. W. Clarke, “The Self Validating Sensor: Rationale, Definitions and Examples”, Control Engineering Practice, vol. 1, no. 4, (**1993**) pp. 585-610.
[3] Z. Feng, Q. Wang and K. Shida, “Design and Implementation of a Self-validating Pressure Sensor,” IEEE Sensors Journal, vol. 9, no. 3, (**2009**), pp. 207-218.
[4] Z. Feng and X. Zhang, “Pneumatic Actuator Fault Diagnosis Based on LS-SVM and SVM”, Chinese Journal of Sensors and Actuators, vol. 26, no. 11, (**2013**), pp. 1610-1616.
[5] J. Ma, K. Karadayi and M. Ali, “Ultrasound phase rotation beamforming on multi-core DSP”, Ultrasonics, vol. 54, no. 1, (**2014**), pp. 99-105.
[6] Q. Li Hou, K.-J. Xu and M. Fang, “A DSP-based signal processing method and system for CMF”, Measurement., vol. 46, no. 7, (**2013**), pp. 2184-2192.
[7] H. Yang, X. Wei and X. Liang, “A SoC and LED based reconfigurable subminiature spectrometer for hand-held measurement applications”, Measurement., vol. 41, no. 1, (**2008**), pp. 44-54.
[8] I. S. Esqueda and H. J. Barnaby, “A Defect-based Compact Modeling Approach for the /Reliability of CMOS Devices and Integrated Circuits”, Solid-State Electronics, vol. 91, (**2014**), pp. 81-86.
[9] Q. Dai, J. Wang and R. Liu, “Research of DSP-based Embedded Systems Connected to the Internet”, International Journal of Hybrid Information Technology, vol. 6, no. 6, (**2013**), pp. 1-10.
[10] S. Engelberg, T. Kaminsky and M. Horesh, “Instrumentation Notes-A USB Enabled, Flash-Disk-Based Data Logger,” IEEE Instrumentation & Measurement Magazie, vol. 10, no. 2, (**2007**), pp. 63-66.

Authors

Zhigang Feng, he is an associate professor of Shenyang Aerospace University. He received his Doctor's Degree from Harbin Institute of Technology, P.R. China at 2009. His main research direction includes system fault diagnosis, self-validating sensor and self-validating actuator.

Meng Qiu, he received the bachelor degree of Computer Science and Technology from TongLing University, China, in 2011. He is currently studying for a master degree in the School of Automation, Shenyang Aerospace University.