Design of high-speed ECT and ERT system

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Abstract. Process tomography technique provides a novel method to investigate the multi-phase flow distribution inside pipe or vessel. Electrical resistance tomography (ERT) and electrical capacitance tomography (ECT) are extensively studied in recent years. As the capacitance to voltage and resistance to voltage converters run faster, the speeds of other circuits in the system, such as MCU, A/D, D/A etc, have become the bottlenecks of improving the speed. This paper describes a new dual-modal, ECT and ERT, data acquisition system. The system is controlled by a digital signal processor. Both the ERT and the ECT systems use one platform to simplify the system design and maintenance. The system can work at high speed which is only limited by the capacitance to voltage converter or resistance to voltage converter. Primary test results show the speed of the new system is 1400 frames/second for 16-electrode ERT and 2200 frames/second for 12-electrode ECT.

1. INTRODUCTION

Electrical process tomography provides a powerful tool for visualize the phase distribution in two-phase flow. Our research group has developed ECT (Wang B.L. et al, 2005, Huang, Z. Y. et al, 2003) and ERT (Zhu J.P. et al, 2005) systems many years ago. They are both controlled by MCS-51 series MCU and use RS232 protocol to send data to PC. However, the two systems are designed in different circuit boards and very difficult to maintain. The two systems work independently and are difficult to precisely synchronize the sampling time. As the capacitance to voltage and resistance to voltage converters run faster, the other circuits in the system, such as A/D, D/A etc, have become the bottlenecks of improving the speed. In order to further improve the system speed, it is necessary to re-design the original ECT and ERT. The first target in the new system design is that the system can work at high speed which is only limited by the capacitance to voltage converter or resistance to voltage converter. The second target is to make the whole system flexible and easy to maintain.

This paper describes a new dual-modal, ECT and ERT, data acquisition system. The system is controlled by a digital signal processor. Both the ERT and the ECT systems use one platform to simplify the system design and maintenance. Primary test results show the speed of the new system is 1400 frames/second for 16-electrode ERT and 2200 frames/second for 12-electrode ECT.

2. SYSTEM DESIGN

2.1 System Platform
The block diagram of most ECT or ERT data acquisition system can be shown in Fig. 1. The difference of the two systems is the front-end signal processing circuit. In ECT, front-end signal processing circuit converts capacitance to voltage. In ERT, it converts resistance to voltage. The other circuits, such as A/D and D/A converter, processor, digital input and output, communication interface and power supply, are almost the same. The new system can be simplified based on the similarity between ECT and ERT.

![Fig. 1 Block diagram of ECT and ERT system](image)

The structure of the new system is shown in Fig. 2. The platforms, inside the dashed lines for both systems, are the same. The circuit modules inside dashed lines in Fig. 2 are corresponding to the circuits inside the dashed lines in Fig. 1.

![Fig. 2 Structure of new ECT and ERT](image)
The platform consists of the following modules: power supply module, processor module, communication module and input and output (I/O) module.

1. **Power supply module**: This module converts the 220V AC power to low voltage DC power for the system. The DC voltages used in the system are +5V, +3.3V, +15V, -15V and an isolated +24V. The DC voltages are distributed to the other modules through the PC104 connector.

2. **Processor module**: The core of this module is a digital signal processor. The whole system is controlled by this module. This module includes DSP (ADSP-2188N), flash ROM and glue logic for the processor to peripherals. The DSP can run at 80 MIPS and integrate 48K words (24-bit) of program RAM and 56K words (16-bit) of data RAM. This chip provides enough processing power for the system.

3. **Communication module**: This module provides USB2.0 interface (CY7C68013A) to the system. The front-end signal processing circuit used in the system runs very fast and thus the communication speed to PC should be very fast. USB2.0 interface can send data to PC at the speed up to, ideally, 480Mbps. Test results show the highest speed of the module is 22Mbps.

4. **I/O module**: The I/O module provides the A/D (AD7472) and D/A (TLV5619) converter and digital input/output capability for the system. A/D converter converts the voltage from the front-end signal processing module to digital signal. The D/A can be used to balance the standing voltage when the measured area is empty. Digital output, implemented in a CPLD (XC9572), can be used to control the operation of front-end circuit and can also provide system status signal. If synchronization is required for multiple system, the digital input can be used to acquire the synchronize signal.

The modules of platform are connected by PC104 connectors. We use PC104 connectors only to connect each module and we defined the signals in each pin of connectors. The system is not compatible with PC104 PC module. The system can be extended easily by adding more new modules if more input signals are needed in the system.

The only difference in the new ECT and ERT system is in the front-end signal processing module. By adding front-end processing circuit for ECT or ERT, this system can operate as ERT system, ECT system or ECT and ERT dual-modal system.

### 2.2 ECT System Design

The main work of ECT system design based on the platform is the designing of front-end processing circuit. The core of the circuit is the capacitance to voltage (C/V) converter. The C/V circuit used in the system is based on differential sampling method (Wang B.L., 2005). Compared to other C/V circuits (Huang S.M., 1992, Yang W.Q., 1994), this circuit can measure the capacitance in one pulse. Fig. 3 shows the principle of the C/V circuit.

![Fig. 3 Principle of differential sampling method](image)

There are 12 electrodes in the ECT system. The front-end signal processing circuit for each electrode is designed in modular fashion. The circuit for each electrode is implemented in one print circuit board (PCB). Each PCB is mounted under the screen of ECT sensor. One flat cable
connects all PCB boards inside the sensor to the platform. The block diagram of front-end module is shown in Fig. 4. The control signals, from the I/O module of platform, and the module address specified by binary-output rotary switch are connected to a decoder. The outputs of the decoder determine whether the module is in excitation mode or measurement mode. The control signals from the I/O module to each front-end module are identical. However the module address of each front-end module can be different. Therefore, modules can be set in different mode.

![Fig.4 Block diagram of ECT front-end module](image)

The modular design of front-end circuit simplified the system maintenance. By changing the number of front-end modules, the system can be use in 8 or 16 electrodes ECT system.

2.3 ERT System Design

The front-end processing circuits of ERT convert the resistance to voltage. The circuit is also designed in modular fashion. The module is designed based on bi-directional current pulse method (Andrew J. et al, 2005). The circuits for 2 electrodes are implemented in one PCB. For 16-electrode ERT system, 8 front-end modules are used. The modules are fixed on the wall of sensor. Each module is connected to a flat cable. One end of the flat cable is connected to the I/O module of the platform. Fig. 5 shows the principle of front-end module based on bi-directional current pulse method.

![Fig. 5 Principle of ERT front-end module](image)

The structure of ERT front-end module is similar to that of ECT front-end module. The control signals, from the I/O module of platform, and the module address specified by binary-output rotary switch are connected to the decoder. The outputs of decoder control the operation of the modules. All PCBs of ERT front-end modules are the same. Each module can be set to different address by the rotary switch.

3. PROTOTYPE SYSTEM AND TEST RESULTS
The new system is assembled after all modules are debugged. In order to test the system performance, the system is operated at ECT and ERT mode separately. First, the ECT system is tested. Fig. 6 shows the ECT system. By placing nylon stick at different positions inside the sensor, we can simulate different flow regimes of two-phase flow. Fig. 7 shows the reconstructed image for stratified flow, annular flow and core flow. Imaging results show that the reconstructed images match with the real flow regimes. The data acquisition speed can reach 2200 frames/s. The capacitance measurement resolution is 1fF.

Fig. 6 ECT system

![ECT system](image)

Fig. 7 Imaging results of ECT

![Imaging results of ECT](image)

Fig. 8 shows the new ERT system based on the platform. The PCBs installed on the sensor pipe are the front-end processing modules for ERT. The low voltage signals induced from the sensor plate have been amplified before they are connected to the flat cable. Test results show that the system can capture the data at the speed of 1400 frames/second. To test the repeatability of the measurement electronics, we use the method in Wang M., 2005. The average standard deviation is 1.5 mV, which is less than 0.13% of typical maximum value in the measurement sequence.

The system performance are tested when the system is work as ECT or ERT. Further work is needed to test the system as dual-modal system. When the system works as dual-modal system we only need to rewrite the program. No more hardware design work is needed.
4. CONCLUSIONS
A novel data acquisition system for ECT and ERT is developed. The system is designed in modular fashion which simplified the system maintenance. A common platform is proposed based on the similarity between ECT and ERT. The platform provides enough processing power for both ECT and ERT and can be extended easily by adding new modules in the platform. The front-end processing modules of ECT and ERT are also designed in modular fashion. All front-end modules in ECT and ERT are connected by a flat cable and are connect to the I/O module respectively. All the signals in the cable are active driven signals. The shielded cable is not needed. This structure simplified the system construction and maintenance. Because DSP, A/D, D/A and the communication interface are very fast, the speed of data acquisition is only limited by the front-end signal processing module. Test results show the ECT and ERT can work at speed of 2200 and 1400 frames/s respectively.

ACKNOWLEDGEMENTS
Project supported by the National Natural Science Foundation of China (No. 60532020,50576084).

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