Development of a PC-based Data Acquisition and Control System

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ABSTRACT

An inexpensive data acquisition and control system, easy to use with different computers, was developed for many agricultural and biological applications. The high-speed data acquisition and control device uses only an RS-232 serial port to interface with a PC. The device has two analog inputs and two analog output channels each with 12-bit resolution. Both voltage output (0-5V) and current output (4-20mA) can be employed with control algorithms for precision control applications. An adjustable voltage reference from 5V to 12V was also provided to meet the excitation voltage requirements of many sensors. The software support developed for this device is a visual window interface.

Keywords: Data acquisition, real-time control, RS-232, PC

1. INTRODUCTION

Personal computers provide high speed, accuracy, flexibility, adaptability, consistency, reliability and mass memory. These features support the mathematics, analysis, storage, display, report generation, control, and communications functions required in today's application. However, most real-world signals (temperature, pressure, flow, speed, intensity, position, etc.) cannot be read directly by personal computers without the use of a PC-based data acquisition and control system.

Data acquisition and control hardware can be classified as external bus or internal bus systems, depending on the method used to interface the hardware with the personal computer (PC). External bus systems may reside in their own enclosures outside the PC. The enclosure provides space for the analog and digital I/O hardware, as well as control circuitry or microcomputer. A power supply may also reside in the enclosure. These systems interface with the PC via a parallel port (standard or enhanced), a serial port (RS-232 or RS422), or an IEEE-488 port. Many external systems also facilitate remote operation. The data acquisition and control system can be placed at a site that is remote from the host computer (and thus close to the field signals). External data acquisition systems can also support a distributed system, in which a large number of parameters can be monitored or controlled, even though they are located physically far from each other and the host computer. The data acquisition system has been broadly used in agricultural application for a few decades. These areas include precision agriculture, weather station, environment control, food processing and safety, air quality, and equipment automation (Chepete and Tsheko, 2006; Lan, et. al., 1997, Lin, et. al., 1998, Lu, 2004; and Munack, 2006)

The internal bus system is a board-level system that plugs directly into the internal computer expansion bus. There are several advantages associated with internal systems. Because an internal system can directly use the computer's resources to program tasks, very high sampling speeds can be reached. Internal systems are lower in cost because the data acquisition and control system can use resources already on the computer. Since the system can use a number of components or functions already in the computer, it does not need its own version of these hardware and software resources. As an example, power can be obtained from the PC power supply, so the internal bus system does not need its own power supply.

Because an internal bus system is not easy to transfer from one computer to another, the external bus system was selected for the development of a data acquisition and control system. The RS-232 serial port is a universal feature of all types of computers and was selected as the communication route for the new data acquisition system.

The objective of this project was to develop a simple PC-based data acquisition and control system that: 1) has a high sampling speed, 2) is flexible enough to accommodate various sensors, 3) is very accurate and 4) is inexpensive. This paper discusses the system hardware, software, and applications.

2. HARDWARE DESIGN

Diagrams of the board-level circuits are shown in Figures 1 and 2. The whole system consists of seven blocks: 1) an RS232 to TTL converter, 2) a two-channel ADC, 3) a two-channel DAC, 4) a signal conditioning block, 5) a voltage/current output and control driving circuit, 6) an excitation voltage output, and 7) a power supply.

2.1 RS232 Port

An RS232 interface passes data in serial via 25-pin D-type connectors. Since all 25 pins are rarely used, a modified version using 9-pin D connector is now commonplace on PCs. Table 1 shows all pin functions and descriptions of each pin. A PC-compatible computer can have up to four RS232 interfaces or communication ports (COM1 to COM4). Each COM port is associated with a UART inside the computer. Operations of the COM port are controlled by internal registers of the UART. The I/O addresses of each internal register are calculated by adding the offset to the base address of a COM port. The base I/O addresses for COM1 to COM4 are summarized in Table 2.

Table 1. RS232 Pin designations.

No. of Pins of 25-Pin	No. of Pins of 9-Pin	Signal Name	Description
1		PG	Protective ground
2	3	TD	Transmit data
3	2	RD	Receive data
4	7	RTS	Request to send
5	8	CTS	Clear to send
6	6	DSR	Data set ready
7	5	GND	Signal ground (common)
8	1	DCD	Data carrier detect
20	4	DTR	Data terminal ready
22	9	RI	Ring indicator
23		DSRD	Data Signal Rate Detector

Table 2. Base I/O Addresses for the PC's COM Ports

Interface Port	Base Addresses	Addresses of Internal Registers
COM1	3F8H	3F8-3FFH
COM2	2F8H	2F8-2FFH
COM3	3E8H	3E8-3EFH
COM4	2E8H	2E8-2EFH

The RS232 port was not used in conventional means by this data acquisition and control system. Instead of using the normal serial-in (RD) and serial-out (TD) lines, the circuit uses other signals to transmit and receive data and to clock the data to and from the ADC and the DAC. The pins of the port are used to provide the following functions to the data acquisition and control system. The request-to-send (RTS) pin and data-terminal-ready (DTR) pin were converted to TTL level using 74HC14 Schmidt triggers, and used to supply serial data and clock signals to our system, respectively. The RS232 control signal CTS input line of the RS232 port was used to read the serial data from the ADC. The signal of the serial port TD output was used to select either the ADC or the DAC to receive or transmit data by a dual D flip-flop of 74HC74.

2.2 ADC and DAC Circuits

The analog to digital converter used was an LTC 1298 micropower successive approximation type (Linear Technology, 1996a). It had 12-bit resolution and required a 2.7 to 6V supply. The typical supply current of the chip was 250:A at a sampling rate of 11 KHz. In standby mode, the power supply current dropped to several nanoamperes. The LTC1298 had two analog inputs, at pin 2 and pin 3, which could be configured into two input modes: single-ended and differential input mode. The LTC1298 communicated with other circuitry through a four-wire serial interface. These four wires were CS/SHDN, CLK, D_{IN} and D_{OUT}. Selection of the chip occurred by making CS/SHDN, (pin 1) low. While the pin is high, the ADC is in standby mode.

This provided a means of controlling the LTC1298 if a number of the chips are connected in a shared bus.

The 12-bit digital-to-analog converter (DAC) LTC1446 outputs voltages that range from 0 to 4.095V in 1mV/LSB steps (Linear Technology, 1996b). It contained two rail to rail output amplifiers, and an internal reference. Because both the LTC 1298 and LTC1446 had the same 3-wire interface wire requirements, they were connected together and a 74HC74 flip-flop was used to select one of them at a time. The two analog output of the LTC1446 were pins 5 and 8. The power consumption of the LTC1446 was a little higher than for the LTC1298. Typical supply current of the LTC1446 was 1000:A at 5V operation.

The ADC and DAC working modes were set using the time sequences of the LTC1298 and LTC1446. The system selected two single-ended inputs for ADC and two single-ended outputs for DAC. During the signal conditioning section, we will discuss how to convert one single-ended to one differential input channel by using a dual precision instrumentation switched-capacitor building block LTC1043. Therefore, we have one single-ended input and one differential input in order to satisfy different needs in this system.

2.3 Signal Conditioning and Control Driving Blocks

One of the two analog inputs was designed to be a differential input (CH0) and the other was designed to be a single-ended input (CH1). A dual precision instrumentation switched-capacitor building block LTC1043 was chosen to allow the ground of the single-ended input to float (Figure 1). The LTC1043 is an excellent chip which has many interesting features. A low power supply and high precision operational amplifier, OP07DP or LTC1077 was selected between LTC1043 and LTC1298. The gain of the amplifier can be set to 100 or 200 with a jumper. The output range of some sensors, thus, the 0-25mV, 0 to 50mV, and 0 to 5V analog signals can be applied into this channel. Due to high gain, the noise or oscillation of the amplifier may degrade the operational amplifier performance in the circuit.

Some excluding interference techniques should be considered to minimize the interference noise. Some possible solutions were employed in the design such as small filter capacitors on both input and output to limit bandwidth, matched metal-film resistors, and good one-point groundings. CH1 of the ADC is used for 0-5V input sensor. The ½ LM358 operational amplifier is used for increasing input impedance of CH1 in order to improve the accuracy of analog signal measurements.

Control driving circuits deal with two analog output channels from DAC LTC1446: CH_A (pin 5) and CH_B (pin 8). CH_B directly connects a MOC2A60-5 power OPTO^{TM} isolator with a two-ampere Zero-Cross Triac output to drive AC power load. The CH_A can connect a ½ LM358 operational amplifier to a programmable, isolated voltage-to-current converter 1B22. The 1B22 converter is pin programmable for 0 to 5V inputs and 4 to 20mA output. The floating 4-20mA output from 1B22 can be used for either control signal or output signal of measurement readings, which can be implemented by programming.

2.4 System Power Supply and Adjustable Reference Voltage Output

Power for the data acquisition and control system was provided by a 9V to 12V with 500mA DC adapter. The accuracy of ADC and DAC directly depends on the precision degree of reference voltage supply (pin 8 of ADC and pin 7 of DAC). For this reason, a LM4040-5 precision micropower shunt voltage reference was used to produce a high precision +5V reference for both the ADC and the DAC. A LM78M05 5V voltage regulator (500mA) was used to power the other chips except ADC and DAC (Figure 2). A DC/DC converter DCP010515DP converted single +5V into ∀ 15V for the 1B22 power requirements. LM317 is a three-terminal adjustable voltage regulator. The adjustable reference voltage output was included by using LM317 (Figure 2).

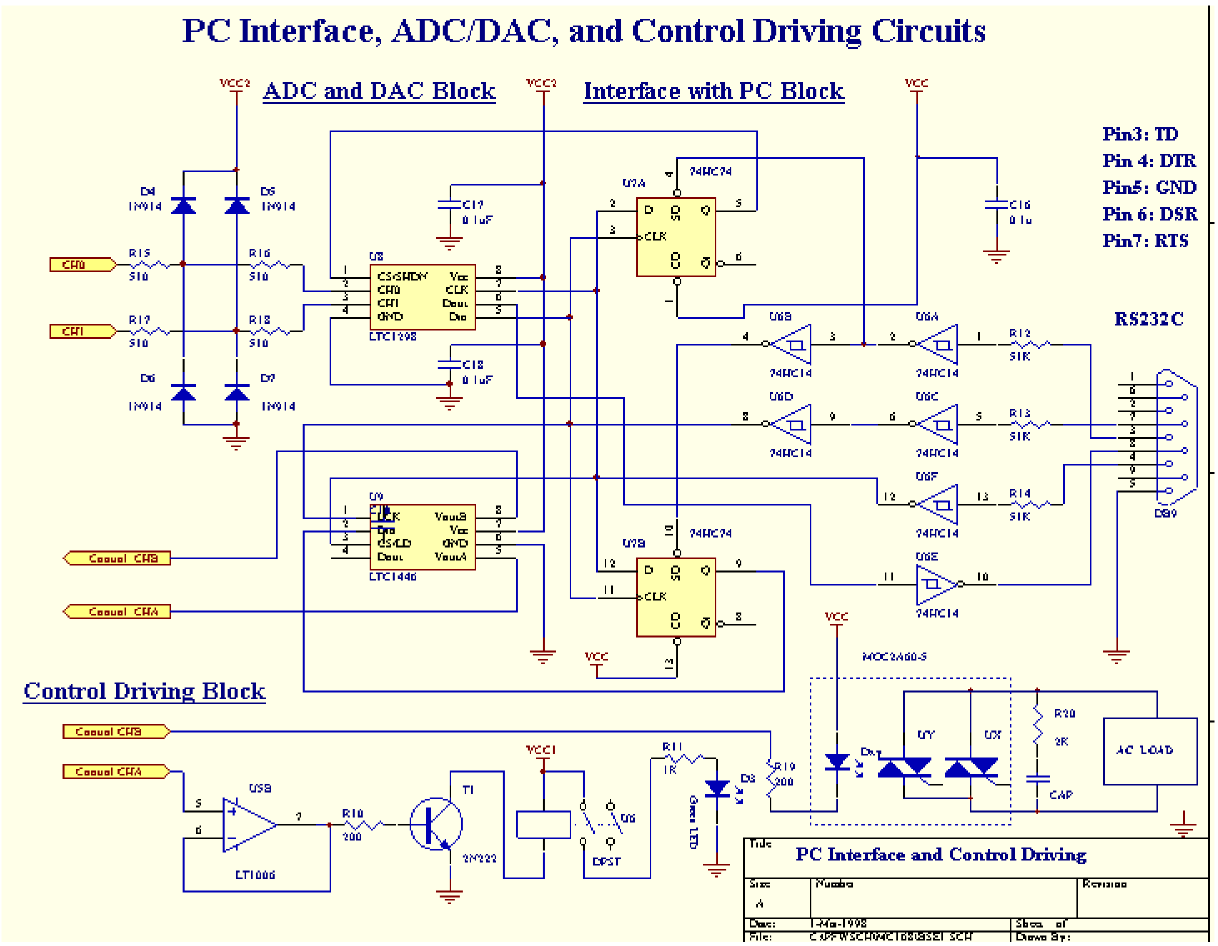

Figure 1. PC Interface, ADC/DAC, and Control Circuits

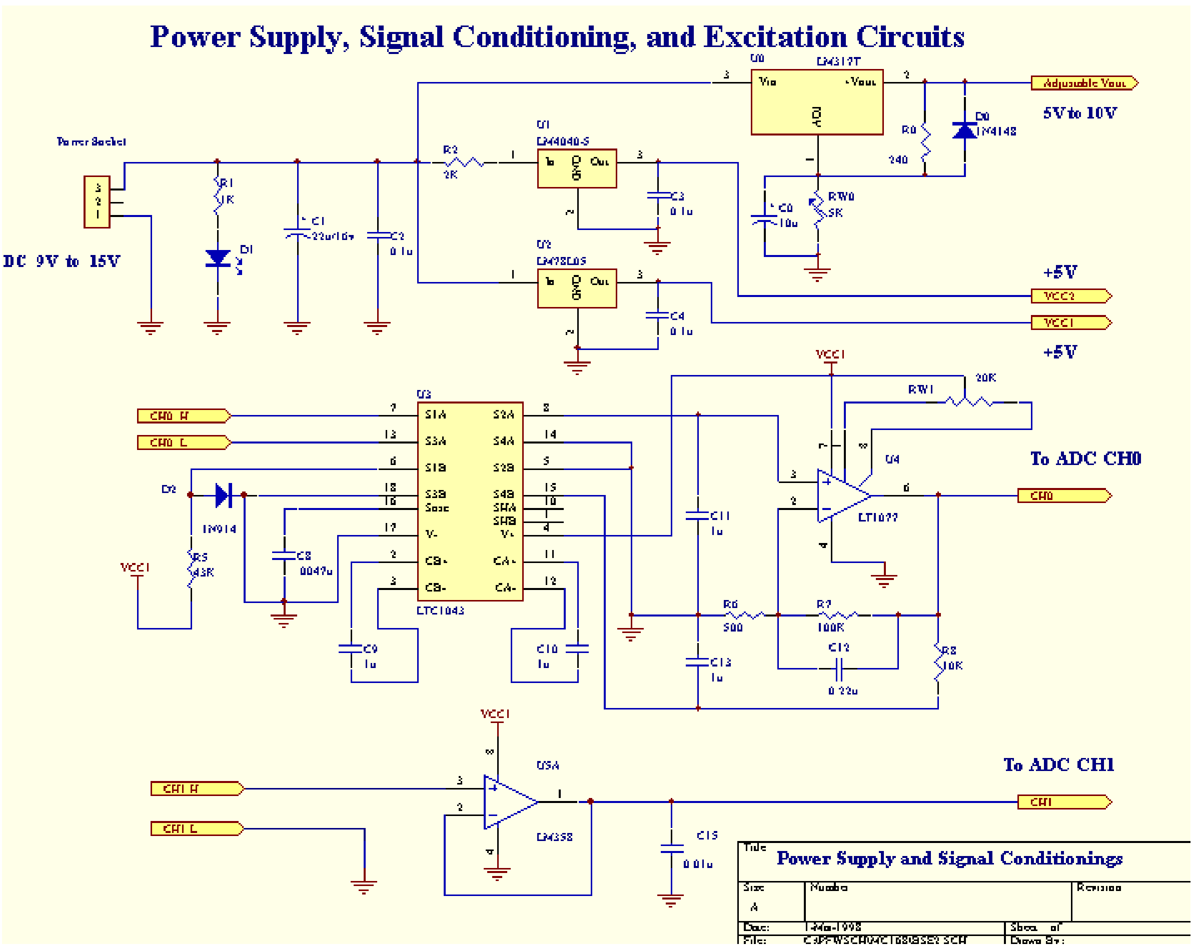

Figure 2. Power Supply, Signal Conditioning, and Excitation Circuits.

3. SOFTWARE DESIGN

The data acquisition and control system software was developed in Visual Basic version 5. Although Visual Basic offers a wide range of program support, there are some functions that are not available. Hardware accesses to ports or to memory locations are two examples of functions that Visual Basic does not support. In addition, the execution time of Visual Basic programs is relatively slow for some specific real time systems. Therefore, it was necessary to use a specialized program to be associated with the hardware and time-saving of data acquisition for this system. A dynamically linked library (DLL) can be used for this purpose written by C++ language in the Microsoft Visual C++ version 5 environments. The Microsoft Visual C++ version 5 provides a simple way to produce a DLL file which can be called by any windows program. It should be noted that a DLL file is an executable program but is not loaded into memory until at least one application needs a procedure contained in the library. Windows examines references to DLL procedures in its programs to determine when a particular DLL is needed for an application. This is why these libraries are called ‘dynamic’. The DLL programming design was mainly based on the ADC and DAC data sheets and their timing sequence diagrams. The DLL program contained many functions such as ADC, DAC, Port-control, and RS232 initialization functions.

The basic protocols of RS232 should be completely understood in order to write DLL programs. The information about RS232 port can be found on the data sheet of the PC87310 dual UART with floppy disk controller and parallel port, which incorporates two full function UARTs, a floppy disk controller(FDC), one parallel port, game port decode, hard disk controller decode, and standard XT/AT address decoding for on-chip functions. The visual window interfaces programmed by the Visual Basic version 5 contain the following functions:

1) Real-time function.
2) Two-analog signal data acquisition.
3) Two-analog control signal output implementation (ON/OFF control, PID control).
4) Real-time data text and graphic monitoring.
5) Data, operating log, and real time information can be stored in the hard disk.
6) Online-recalibration if the measurement needs for specific sensors.
7) Online helps.

4. SYSTEM EVALUATION

The data acquisition and control system was used for measuring air temperature using a thermistor and humidity measurement for about one month. This data acquisition and control system can be used in various interfacing applications. A circuit board, as shown in Figure 3, based on this study was designed for measuring methanol concentration. The components were purchased from Digi-Key Corp. and Linear Technology. Figure 4 shows the flowchart for connecting the circuit board with methanol sensor. The methanol concentration monitor and control instrument was developed based on this simple data acquisition system. By attaching suitable sensors, temperature, humidity, pressure, magnetic field intensity, flow rate, position, etc., can be recorded via two analog input channels. The control system in this device is relatively easy to implement all kinds of control algorithms. Two analog output channels can provide high performance control tasks.

5. **CONCLUSIONS**

A data acquisition and control system, easy to use with different computers, was developed for many agricultural and biological applications. The high-speed data acquisition and control device uses only an RS-232 serial port to interface with a PC. The device has two analog inputs and two analog output channels each with 12-bit resolution. Both voltage output (0-5V) and current output (4-20mA) can be employed with control algorithms for precision control applications. An adjustable voltage reference from 5V to 12V was also provided to meet the excitation voltage requirements of many sensors. The software support developed for this device is a visual window interface. The system costs about $95. The system was further developed for a methanol concentration and controller. The system can be used for many practical applications in agricultural and environmental fields.

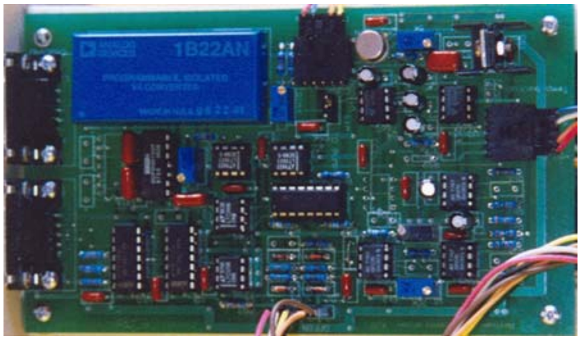

Figure 3. Photo of the circuit board.

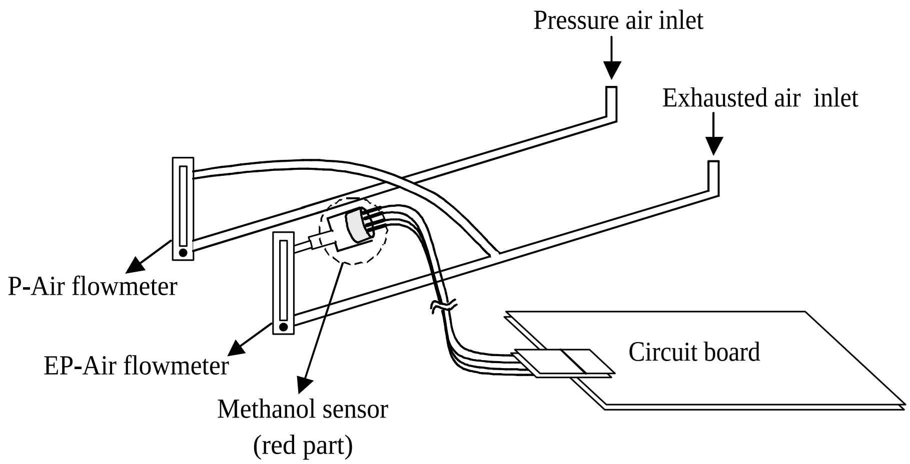

Figure 4. Flowchart for connecting the circuit.

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