

# Real-time Data Collections and Processing in Open-loop and Closed-loop Systems

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## Abstract

We present our new pedagogy for teaching data processing implementations using the LabVIEW program and DAQ (Data Acquisition) board. In the Electrical Engineering (EE) and Electrical Engineering Technology (EET) curricula, the LabVIEW program and DAQ board data acquisition have been used as an effective platform for teaching signal processing and control systems during junior year. Such courses are offered in both EE and EET programs based on current trends in the signal processing/control industry and student interest regarding career development. The courses have significant emphasis on real-time processing applications. After completing the course, students not only became familiar with MATLAB and LabVIEW software development tools, but also gained real-time experience in signal processing. They are now able to design low-pass and band-pass filters and implement them using MATLAB and LabVIEW software, and thus can apply the software and hardware interface for real world applications. Compared to traditional control or signal processing courses, which mainly focus on heavy mathematical development with limited opportunity for computer simulations, our real-time projects can greatly help students understand how a real-time signal such as a temperature signal can be processed and controlled in a closed-loop feedback control system, or how his/her own voice could be enhanced by the following stages: audio amplification, audio digitization and collection by a DAQ board, display by LabVIEW and spectrum analyzer, digital audio processing by MATLAB and LabVIEW software, and analog audio recovery by an active reconstruction low-pass filter in an open-loop system. Therefore, in this paper, we first introduce a closed-loop temperature control system which includes a DAQ board interface circuit and LabVIEW software. Next, we propose a DSP (Digital Signal Processing) platform to perform real-time audio data processing. Using these proposed platforms, students successfully learn LabVIEW and DAQ board interfacing techniques and are able to apply them to real life applications after completing such projects.

## I. Introduction

Data acquisition and data/signal processing technology have continually impacted electrical, computer, and biomedical programs. This is due to the fact that real-time processing plays a key role in many current applications of electronics and control systems. A quick review of

the current jobs advertised in technical magazines and on internet sites further reveals a demand for individuals with a refined knowledge of real-time processing. Hence, being adequately qualified in operating, maintaining, repairing, evaluating, and helping to specify and design real-time systems allows a student to demonstrate significant competency for employment.

To prepare engineering/technology students for such an industrial trend, many undergraduate programs in engineering/technology not only offer a course to cover the fundamentals of signal and system analysis, but also provide a second course in which real-time applications and corresponding advanced topics such as speech signal processing, adaptive filtering, and closed-loop control systems[1-3,5] are introduced.

A control course in our engineering program and a signal processing course in our technology program are designed for junior students to gain experience with real-time data/signal processing and to develop interest in real world applications. Such examples of projects offered include a closed-loop temperature control system and an innovative real-time speech processing project, which are covered in this paper. Our complete real-time processing system which includes design and testing greatly motivates students and allows students to better understand class topics, whereas traditional teaching only focuses on heavy mathematical development in signal sampling and recovering, spectrum analysis, closed-loop system analysis, and FIR or IIR filter design with limited opportunity for computer simulations. Our course assumes that students have already acquired working knowledge of the Laplace transform, Fourier analysis, and analog filters from the previous course. In addition, proficiency in MATLAB programming is required, and MultiSIM will be used to verify different filter designs. In offering a broad coverage of topics and a focus on real-time applications, the course could prove to be beneficial to all electrical engineering students.

Since teaching advanced real-time processing topics has a requirement of being taught at a hands-on level, adopting traditional teaching approaches and using textbooks from a standard four-year program that focus on complicated mathematics and theories may not be appropriate. Hence, in this paper, we will present our innovative pedagogies and experiences in the engineering/technology curricula.

The paper is organized as follows. We first present a closed-loop temperature control project in the EE program; then, we demonstrate a hands-on signal processing project in the EET program. Note that both projects use DAQ (Data Acquisition) boards and simulation tools such as LabVIEW, MATLAB and MultiSIM. Finally, we address possible improvement of the course contents and associated laboratories.

## **II. A Closed-loop Temperature Control System**

In this section, we create an on/off closed-loop temperature control system which includes two SCR's (silicon controlled rectifiers), an LM34DZ temperature sensor, two diodes and one 10 ohm resistor heater. We use *LabVIEW* to apply 10V power to the heater resistor until its temperature reaches 100 degrees Fahrenheit. Then the SCR will turn off its power supply until the resistor cools to less than 90 degrees Fahrenheit. The system will then turn the

power back on the heater to raise the temperature again. Therefore, this closed-loop control system can keep the temperature between 90 and 100 degrees Fahrenheit.

### A. System Level Concept

Figure 1 shows the system block diagram, where the design specifications are given and LabVIEW is required for data acquisition and processing.

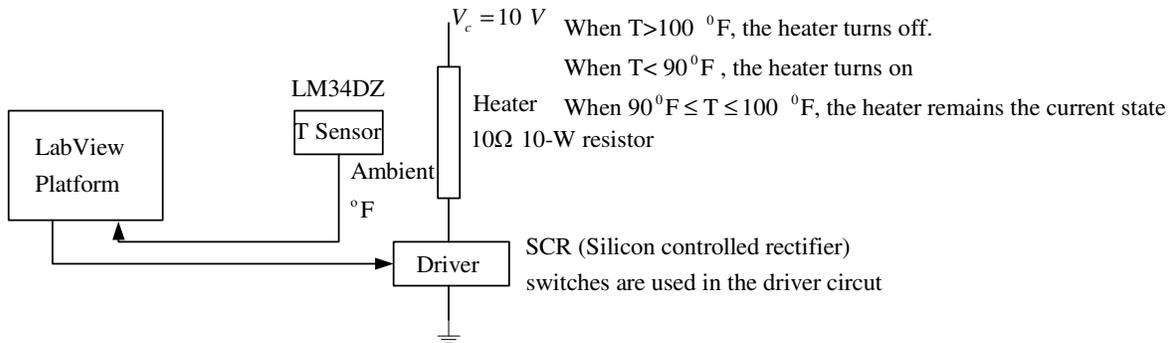


Figure 1. On/off Closed-loop Temperature Control

### B. Hardware Design

The hardware design and interface with LabVIEW is shown in Figure 2. As shown in Figure 2, the special elements used in this project include: an LM34Z temperature sensor, an SCR (silicon controlled rectifier, often used in power industrial electronics such as automobiles), a diode, and a 4N33 optoisolator.

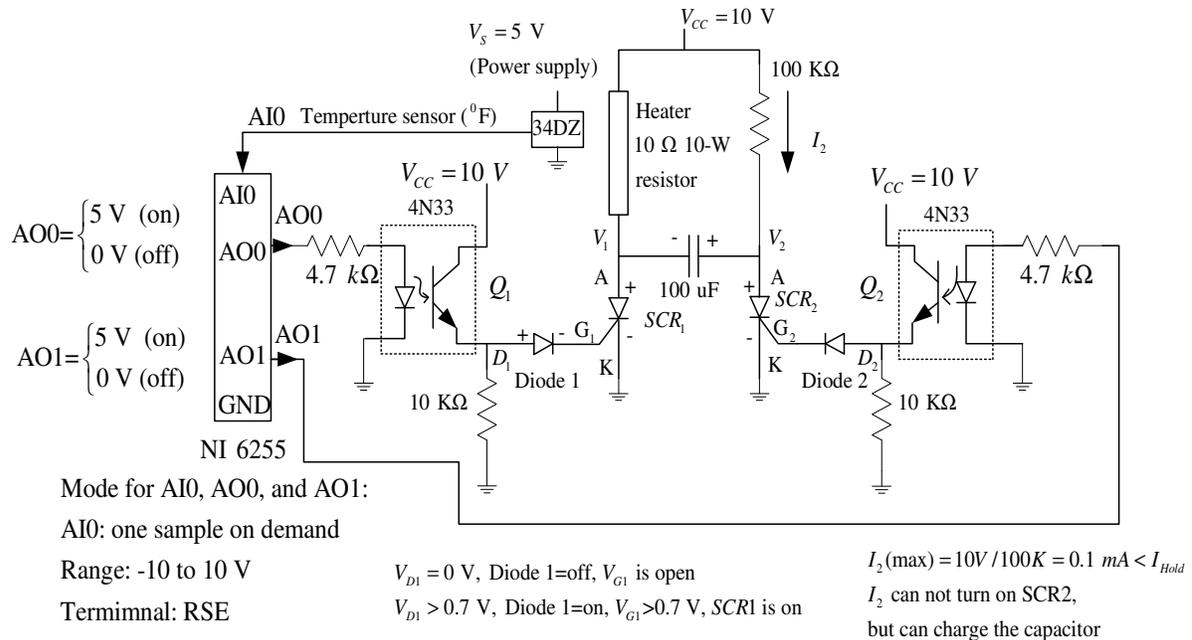


Figure 2. Schematic of An On/Off Closed-loop Temperature Control System

When the temperature sensor detects that the ambient temperature is lower than  $90^{\circ}\text{F}$ , the LabVIEW DAC channels 0 and 1 output  $\text{AO0}=5 \text{ V}$  and  $\text{AO1}=0 \text{ V}$ , respectively. This causes the SCR 1 on to turn run the heater. Otherwise, the SCR is off. The capacitor is charged to 10 volts, that is,  $V_2 - V_1 = 10 \text{ V}$ . When the temperature is between  $90^{\circ}\text{F}$  and  $100^{\circ}\text{F}$ , the LabVIEW DAC channels 0 and 1 output zero volts, that is,  $\text{AO0}=0 \text{ V}$  and  $\text{AO1}=0 \text{ V}$ . SCR 1 is still on since the current passing through is greater than the holding current, and SCR 2 remains in the off-condition. However, when the temperature is over  $100^{\circ}\text{F}$ , the LabVIEW ADC channels 0 and 1 output  $\text{AO0}=0 \text{ V}$  and  $\text{AO1}=5 \text{ V}$ , respectively. This turns on SCR 2 and forces SCR 1 to be turned off. C is discharged from the path (current flow)  $V_{cc} - V_1 - V_2 - K - \text{Ground}$ . After C is fully discharged, C acts as an open circuit. The small holding current cannot maintain the current conducting through SCR 2. Thus, both SCR1 and SCR2 are now off. When temperature is less than  $90^{\circ}\text{F}$ , this procedure repeats from step 1.

### C. Software Design and Algorithm

Figure 3 shows the front panel requirement and Figure 4 describes an algorithm for converting the temperature sensor voltage to display temperature in degrees Fahrenheit and degrees Celsius.

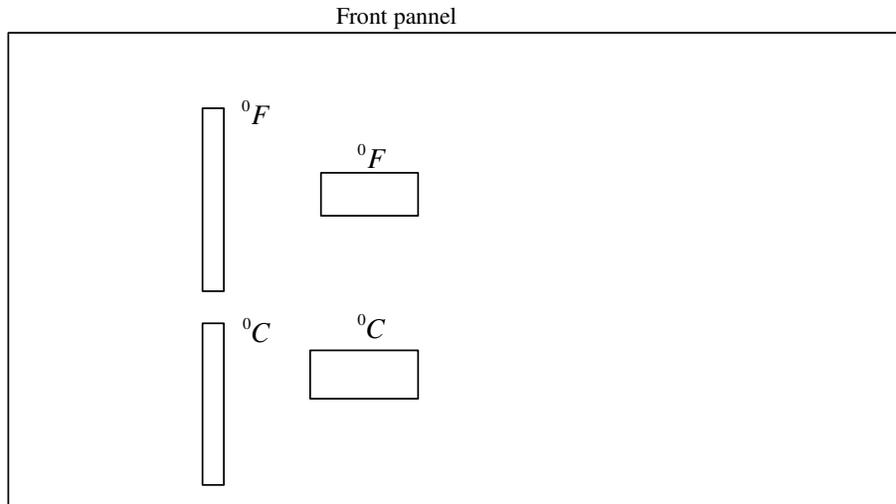


Figure 3. LabVIEW Front Panel

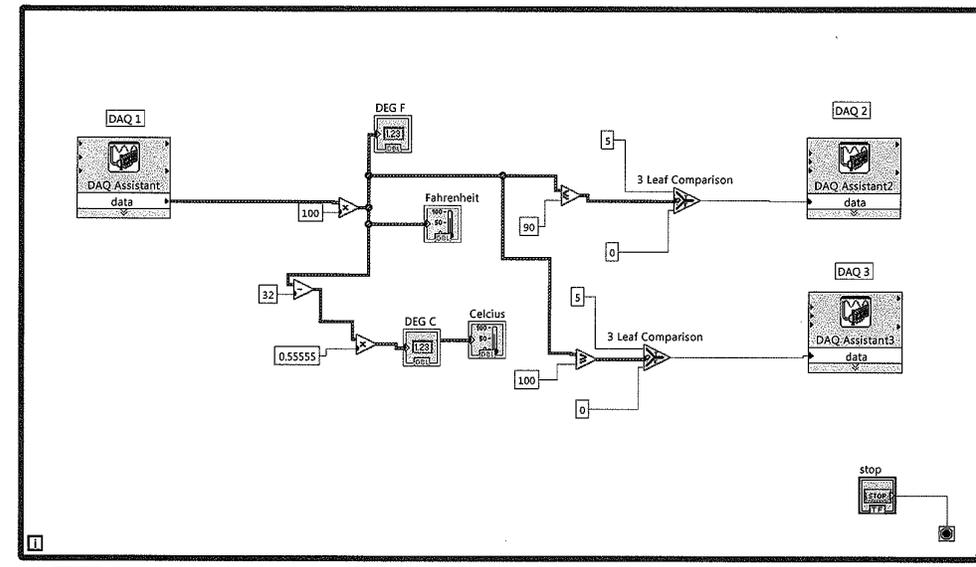


Figure 4. Sample of the LabVIEW Program

In summary, students were asked to design and construct the circuit, utilize LabVIEW to power and control the heater, and display the temperature in degrees Fahrenheit and degrees

Celsius. Then, students examined the operation of the circuit by charting the temperature every five seconds in degrees Fahrenheit and drawing the results for two complete cycles of the temperature control for the system.

### III. A Real-Time Speech Processing System

We now focus on a real-time speech project for the EET program in which the DSP (digital signal processing) technique will be used. The textbook selected was “Digital Signal Processing: Fundamentals and Applications.” published by Elsevier, 2013 [1]. The textbook presents course materials at an appropriate math level, uses an ample amount of simplified and clearly worked examples, adopts MATLAB programs to demonstrate simulations, and provides application examples to motivate students. Simplification of real-time DSP implementations to the engineering technology level is a plus. To minimize the time required to learn different simulation tools, we simply selected MATLAB, which students had gained familiarity with when they took the first signal processing course as a major simulation and design tool. However, other simulation tools were also welcomed when time permitted.

A PCI-1200 DAQ board and LabVIEW were chosen as a platform for teaching real-time signal processing. Students gained working knowledge upon completing their project. We requested the students to design an FIR low-pass filter and an IIR band-pass filter using MATLAB, and then to apply the results to LabVIEW programs to process his/her own audio signal sampled from a microphone. Meanwhile, the original speech spectrum and the processed speech spectrum were obtained and displayed by LabVIEW for comparison.

### Real-Time Digital System Implementations

A. We first introduce a tutorial to verify data acquisition in the system to help students to establish working knowledge.

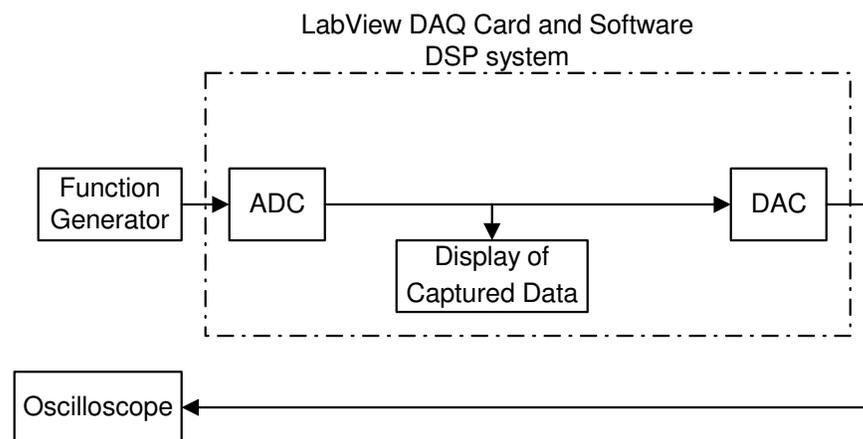


Figure 5. Real-time DSP Laboratory Setup

The laboratory setup is shown in Figure 5 so that the students can verify the sampling and recovering process and gain control of the analog-to-digital conversion (ADC) input and digital-to-analog conversion (DAC) output via the DAQ card.

**B.** Design and construct a signal conditioning circuit (an audio amplifier using LM386 with a gain of 200) and put it into the audio system using a microphone as the input, as shown in Figure 6.

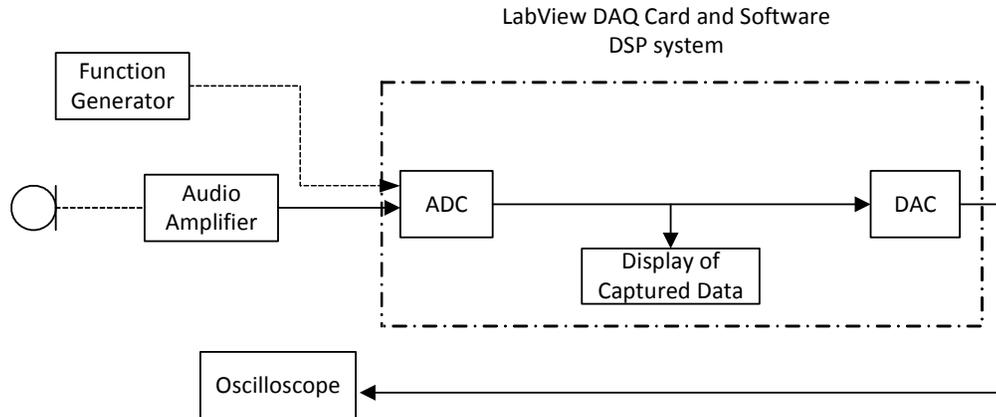


Figure 6. Test of Audio Amplifier

**C.** Design and construct a second-order low-pass Sallen and Key Filter with a cut-off frequency of 3,200 Hz and connect it into the audio system, as shown in Figure 7.

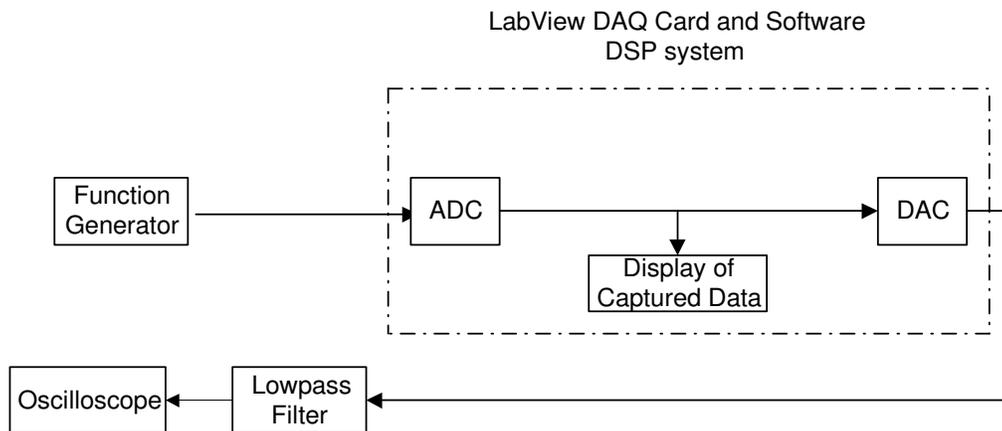


Figure 7. Test of the Low-pass Filter

#### D. FIR filter design and implementation

First, design a low-pass FIR filter using the Hamming window design method by MATLAB. Then apply the filter coefficients from MATLAB for a digital filter created in LabVIEW.

The filter has 15 taps, a cut-off frequency of 800 Hz, and a sampling rate of 8,000 Hz. This low-pass FIR filter can effectively remove the high-frequency background noise.

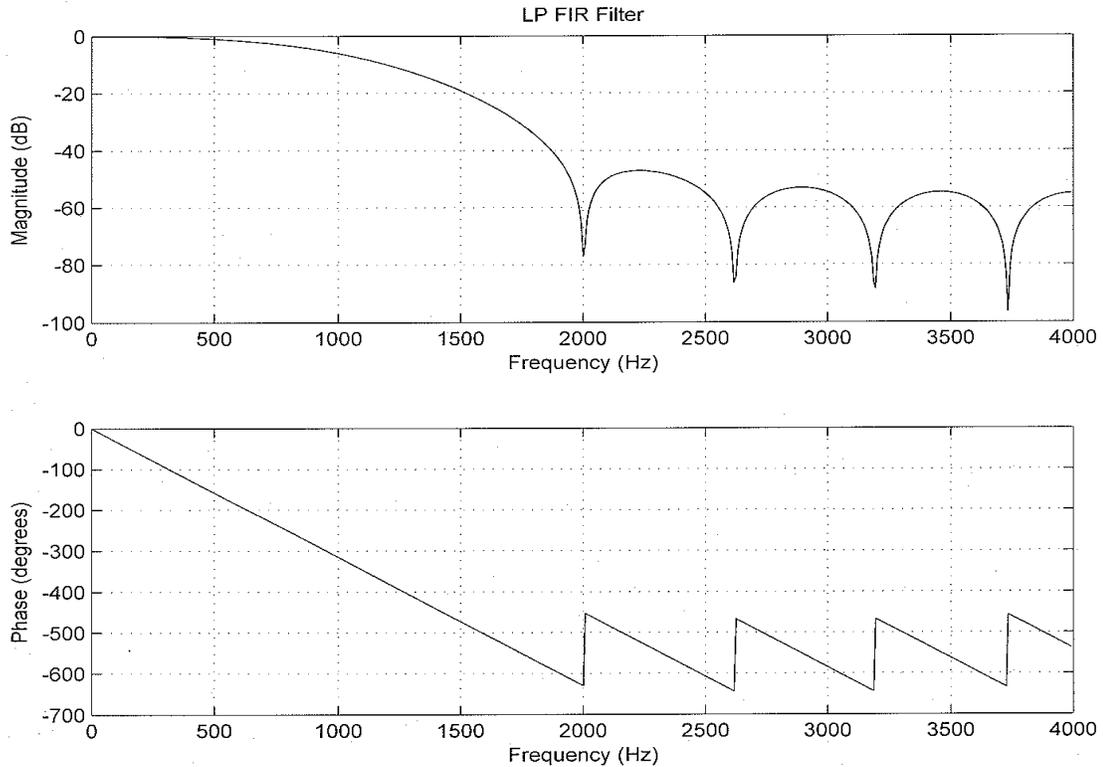


Figure 8a. Frequency Responses of the Low-pass FIR Filter by MATLAB

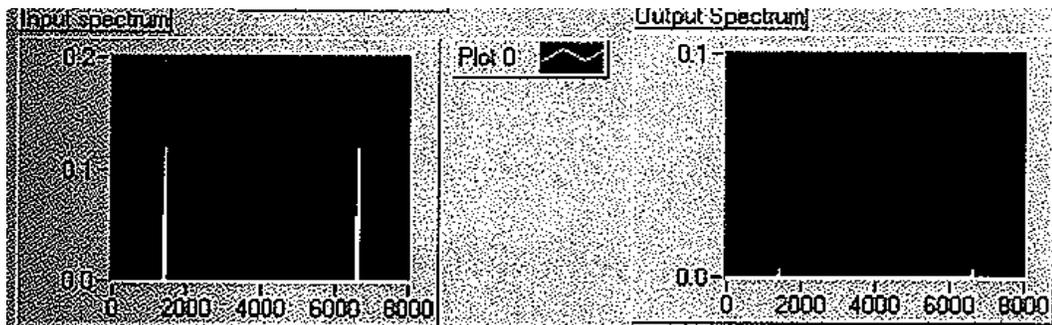
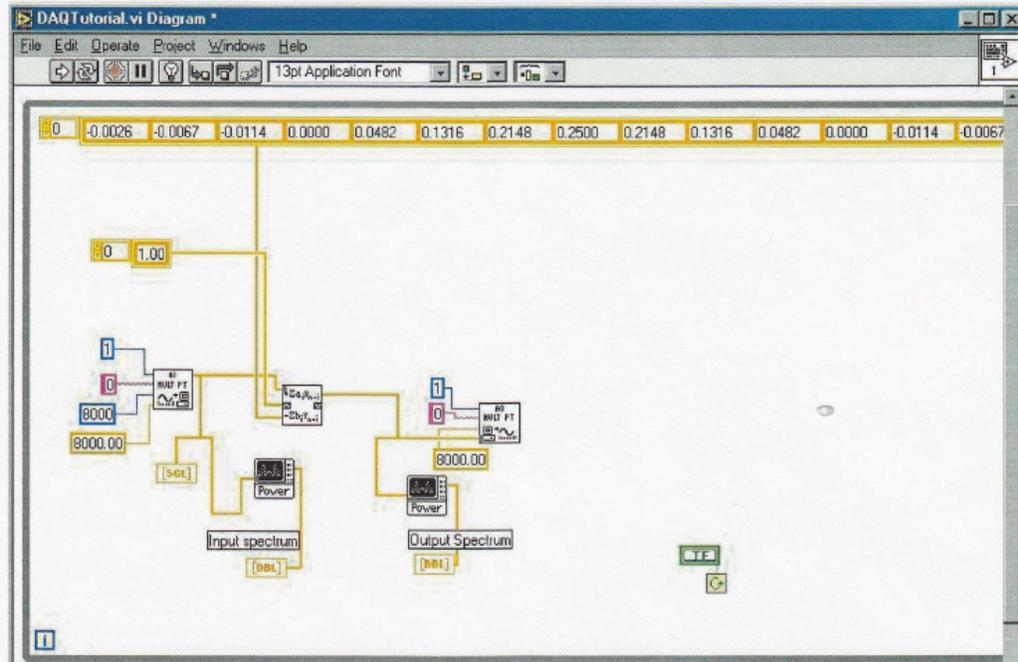


Figure 8b. Low-pass Filter Implementation by LabVIEW

### E. IIR filter design and implementation

First, create a band-pass IIR filter using the bilinear-transform method. This is a second order Butterworth filter that passes frequencies between 1,200 Hz and 1,600 Hz. A sampling rate of 8,000 Hz is used.

Then apply the filter coefficients from MATLAB for a digital filter created in LabVIEW.

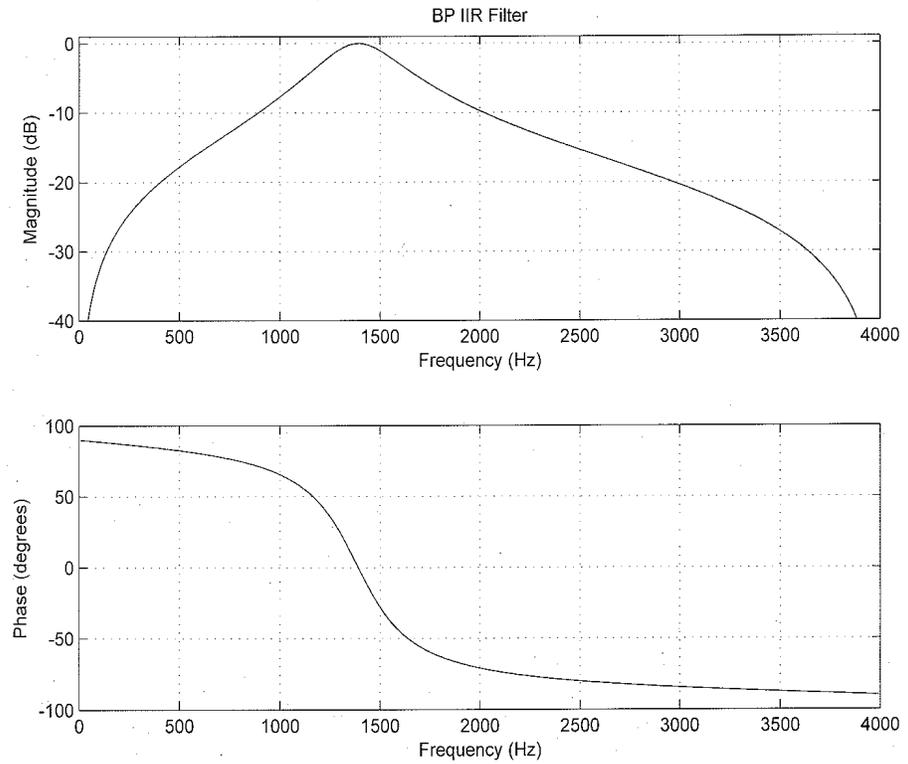
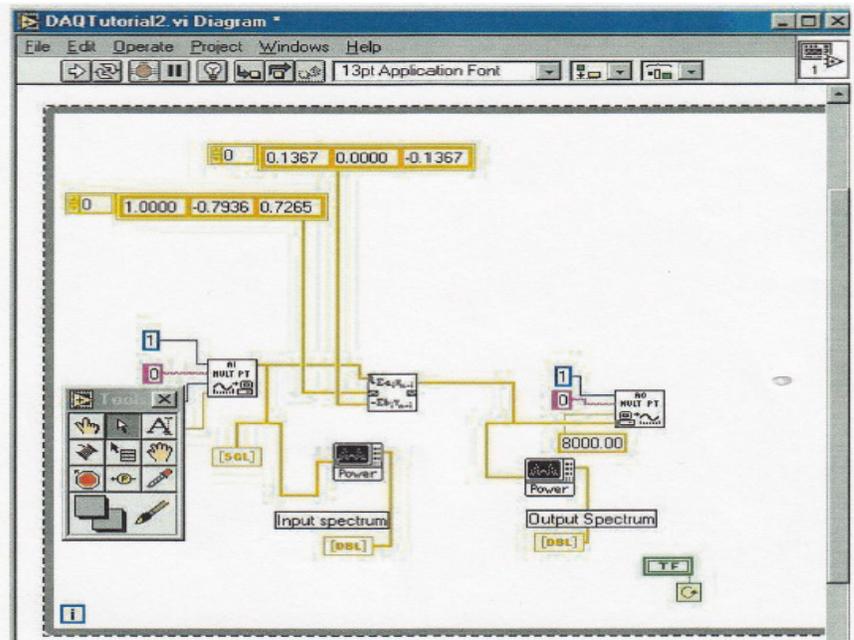


Figure 9a. Frequency Responses of the Band-pass Filter by MATLAB



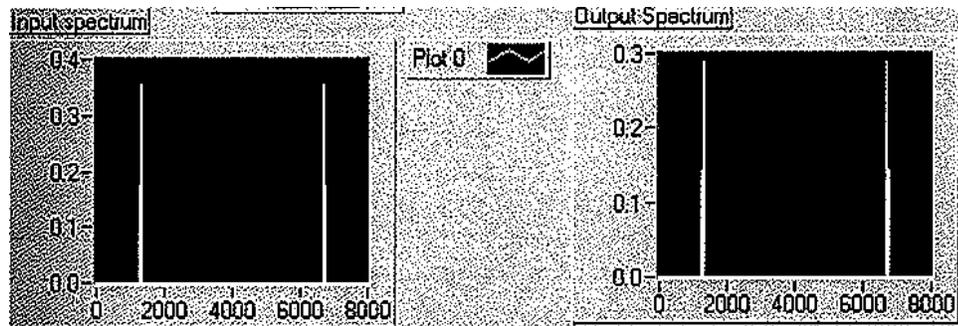


Figure 9b. Band-pass Filter Implementation by LabVIEW

## F. The complete system

Finally, a complete audio system as shown in Figure 10 is established and the snapshot of its hardware realization is shown in Figure 11.

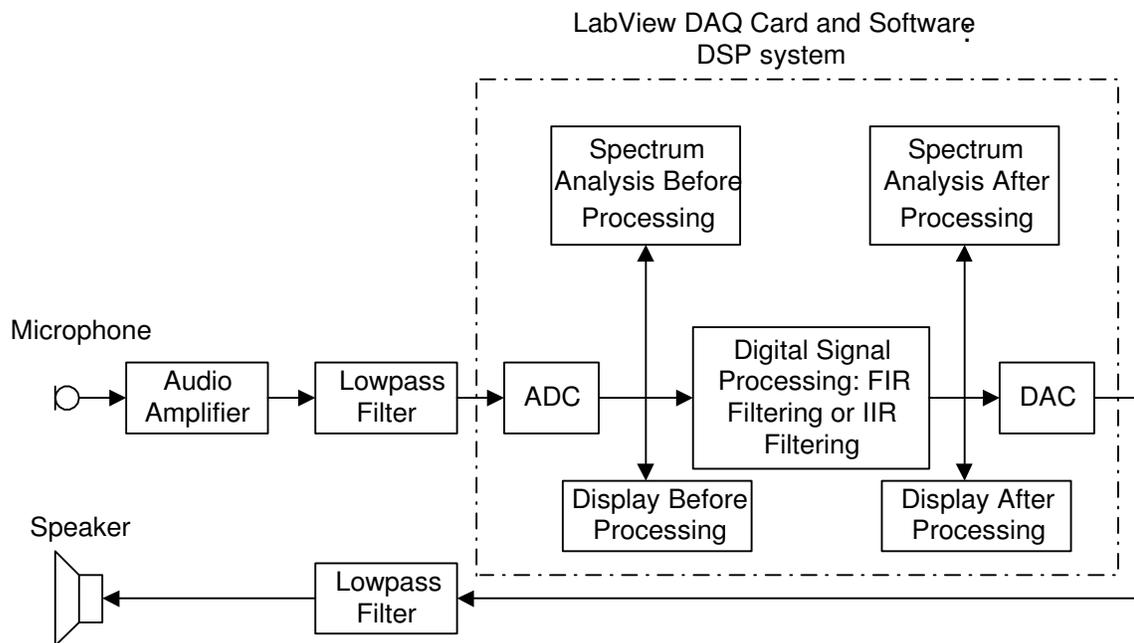


Figure 10. The Overall Speech Processing System

To determine the functionality of the project, allow speech input from a microphone and output to a speaker. Then test the program by inputting signals at various frequencies. Next, examine speech through each filter: the low-pass filter cuts off high-end frequencies, making voices sound muffled; the band-pass filter makes speech samples sound watered down by only passing a small range of frequencies.

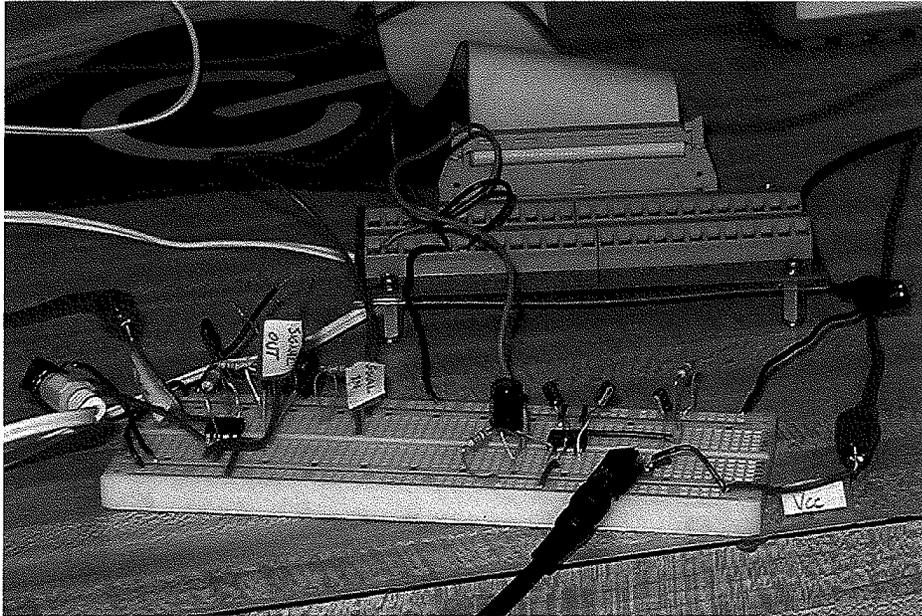


Figure 11. Snapshot of the Hardware Realization

In summary, students were asked to use the MATLAB tool to perform filter design, digital filtering, and spectral analysis of the input and output signals to examine the effects of filtering. Students can also compare the calculated spectrum of the original speech to that of the filtered speech. Meanwhile, the students examined the filtered speech by listening to the processed sound and comparing it with his/her original voice.

#### **IV. Future Improvement**

Based on our experiences from teaching real-time implementation courses, we felt that for all the lectures containing well-established topics such as closed-loop system analysis and the digital spectrum, FIR and IIR filter implementations and developed laboratories are suitable. We have successfully delivered course materials with an emphasis on principles and hands-on applications as opposed to heavy theory. On the other hand, based on the current industrial trend, we could improve the course by introducing additional topics such as adaptive filtering, subband coding, and wavelet coding (as well as its applications). To improve our labs, we should make use of the lab equipment fund to adopt more advanced data processing platforms with multi-channel ADCs and DACs so that many practical real-time laboratory projects can be developed.

#### **V. Conclusions**

The industry has shown a continuous demand for engineering/technology students to possess a working knowledge of advanced and real-time techniques. The traditional

treatment of teaching those subjects using profound mathematics is not appropriate. However, with mathematical simplifications equipped with numerical examples, MATLAB simulations, and real-time laboratories, both engineering and technology students are able to grasp concepts effectively and thus apply their obtained knowledge towards their careers and future technical practices.

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## Biographies

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