

Process Control Laboratory Experiments Using LabVIEW

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Abstract

The process control laboratory course in Chemical Engineering at Michigan Tech was recently restructured to teach students how to operate cutting edge computer-based systems, and to integrate this knowledge with process control theory. The laboratory equipment, as well as the structure of the course and the lectures, were redesigned to accommodate in-line digital computer control.

Three processes reflecting the unit operations commonly found in modern chemical manufacturing plants were implemented in the restructured laboratory: a bench scale house model for temperature control, an air-pressure tank farm for relative gain analysis and decoupling, and two interacting water tanks for multiple and cascade control. To add to these three processes, the implementation for a separation process is currently being designed. These laboratory experiments have sensors (temperature, pressure, flow, and level) for data acquisition and final control elements.

Stand-alone control stations are used to govern each process. Each station has a PC with Windows NT (4.0), an Intel Pentium-II 266 PCI motherboard, 64 MB RAM, a 3.5" diskette drive, a 100 MB zip drive, a 3.2G hard disk, a high resolution monitor, and a printer. Two interface cards are installed in each computer: one for input signals and another for output signals. Interfacing, data acquisition, analysis, and presentation are carried out using the graphical programming language LabVIEW (National Instruments).

Thirteen control experiments were designed to be performed by students in the process control laboratory course using this setup. Students who have taken the course have responded positively to the course, particularly to the use of functional icons. They find graphical programming to be an attractive alternative to programming in code. The analysis and presentation of real-time dynamic data can be effectively accomplished using functional icons, which allow for simple and straightforward presentation of control concepts.

1. Introduction

The Department of Chemical Engineering has constructed a chemical processing pilot plant and simulation laboratory, dubbed the Process Simulation and Control Center (PSCC). This facility integrates a multipurpose pilot plant and a Honeywell TDC-3000 (Total Distributed Control) system. The current version has three processes: 1. a 30-gallon CSTR system (batch or continuous), 2. a solvent recovery process, and 3. a fractional crystallization process. The first two processes have been completed and are now integral parts of the Unit Operations Laboratory, a required course for seniors majoring in Chemical Engineering [Kim and Caspary, 1993, and Pintar et. al., 1998]. The third process is currently in the design stage and awaits funding.

Engineers with knowledge of how to operate state of the art control systems have been in increasing demand in the industrial sector. To increase our students' competitiveness in the job market, the Process Control Laboratory course was upgraded in 1994 from a 3-credit optional course to a 4-credit mandatory course.

We offer a series of three courses in process control: two undergraduate courses (one required theory and one optional laboratory) and one graduate course:

CM3310 Process Control [3 cr: 3-0-0 (Lac-Rec-Lab)]

CM4955 Process Control Laboratory [3 cr: 2-0-3]

CM5680 Advanced Process Control [3 cr: 3-0-0]

The first introductory course is offered once a year to juniors in the Spring semester and the subsequent optional laboratory course is offered once every two years to seniors in the Fall semester. The laboratory course helps students prepare themselves for the dynamic behavior and control aspects of the Unit Operations Lab experiments.

2. Course content

The topics covered in a typical semester are shown in Table I. The major objectives are to solidify students' understanding of the feedback control concepts taught in CM3310, and to introduce them to some advanced control theory and applications.

Table I. Course Outline

1. Review and introduction
 - Review of a PID feedback control theory
 - Description of the computer and interface hardware
 - Programming language: LabVIEW of National Instruments
2. Sample Data Control System

- Inevitable noise in signal and digital filters
- Z transforms and inversion
- Conversion between continuous time, discrete time,
and Laplace domain
- 3. Digital control algorithms
 - Sampling time and stability
 - Digital PID controller
 - Deadbeat and Dahlin algorithm
 - Ringling effect and correction
- 4. Advanced control concepts
 - Cascade, feedforward, feedforward with feedback trim,
Smith predictor and IMC, interacting multivariable control,
Statistical process control, fuzzy logic control.
- 5. Projects

The lab experiments are coordinated with the lecture topics so that the students will see theory in action. For example, lectures on statistical process control help the students get acquainted with sampling frequency, mean-range charts, and relative precision process capability indexes before they carry out lab experiments.

3. Real-time Digital Control System

Each computer workstation consists of the following items.

Microcomputer

There are seven PC workstations in the lab for weekly hands-on experiments. Each is equipped with the following:

- Intel Pentium microprocessor running at 250 MHz with 16M RAM
- Two PCI/IDE peripheral channels for hard drive, CD-ROM drive, Zip 100 drive
- SVGA color 13" monitor (1024x768)
- Platform: Windows NT (4.0)

Interface cards

Each computer has plug-in boards (manufactured by National Instruments) to handle input and output signals. These include the following:

- 1 AT MIO16L9 for the input signals
- 1 AT AO6 for the output signals

Alternatively, SC-2070 (Input terminal) and CB-50 (Output terminal) boards are recommended for easy handling of I/O wires. Each station is equipped with a power source (24V@4.8A) for signal generation.

Program

LabVIEW (current version 5.0) is a graphical programming tool. The term LabVIEW is an acronym for **L**aboratory **V**irtual **I**nstrument **E**ngineering **W**orkbench (Johnson, 1995).

Programs ranging from a simple function to a very sophisticated control system can be implemented by constructing block diagrams. A block diagram consists of icons and “wires” (lines) that may be placed to connect the icons in a specific way. The software automatically converts the interconnected icons into executable codes, simultaneously reporting any errors encountered. Its corresponding front panel serves as a virtual instrument (vi), mimicking the real instrument. The vi allows us to convert a computer into a useful instrument for measuring variables. It can also create a virtual strip chart recorder. There are over 800 icons available in the program, and more icons can be created for use in specific cases.

Processes

Three processes have been designed and fabricated by the in-house master mechanic of the department:

- Two-air pressure tanks in series or parallel
- Two-liquid storage tanks in series or parallel
- Model house with a window and a chimney.

Figure 1 shows a flow sheet for two liquid storage tanks. A digital snapshot is shown in **Figure 2**. A wiring diagram illustrating the power source is shown in **Figure 3** for those who are interested in implementing a current signal (mA).

4. Experiments

Old Experiments

From 1985 through 1993 the laboratory experiments for the course were updated yearly as our limited budget allowed. Some of the key experiments included the following:

- Data acquisition using the microprocessor
- Control valve characteristics for air/water flow systems
- Pneumatic analog controller characteristics
- Simulation of PID controller tuning with the Electronic Process Simulator (manufactured by Foxboro)
- Application of DDC to the heat exchanger (PC with Keithley DAS),
- Modeling of an electric furnace for calibration of thermocouples
- Tuning of the interacting control loops of the bio-reactor

Students were exposed to numerous lectures and exercises on programming in machine language and either BASIC or FORTRAN prior to their participation in these lab experiments.

New Experiments

Introducing the Honeywell TDC-3000 System to the UO Lab experiments in 1993 allowed for a complete restructuring of the control lab experiments. This system, coupled with compact pilot plant-scale processes, allowed students to easily observe the dynamic behavior of control valves and related process dynamics. The same final control elements and most of the sensors (such as Honeywell’s “smart” transducers used in the UO Lab experiments) were used in the control lab experiments to familiarize students with the special hardware and programming options used in real-time operations.

Since programming in LabVIEW is distinctly different from using conventional programming languages such as BASIC and FORTRAN, the lab manual was totally rewritten to accommodate the change. The course content for lectures and lab experiments (Table II) was reformulated to give students balanced exposure to both theory and direct real-time digital control.

Table II. Weekly Experiment Topics

1. Computer station assignment and Introduction:
Processes, interface boards, and LabVIEW icons
2. Data Acquisition, Analysis, and Presentation
Step by step programming techniques:
Data acquisition
Voltage/current data presentation: strip chart
Storage: MS Excel
3. Signal Processing
Noise/Gaussian white noise
Performance of digital filters
4. Feedback Control
Characterization of a control valve
House temperature control
Interacting two water tank control
Cascade control
Tuning of controller parameters
Observing ringing effects/stability
5. Statistical process control

The lectures and ten laboratory experiments were structured to complement each other. In the lab, a group of two or three students is assigned to each computer station. The members of each group carry out experiments together throughout the term. Lab reports and assigned problem sets are also prepared by group, and the members of each group share the grade for each assignment.

Selected experiments from the new laboratory course are discussed in more detail below.

Signal processing

In this experiment the students create a program that measures temperature using a thermocouple, adds noise to the temperature signal, and then filters out the noise. They also smooth out the signal with (1) statistical methods and (2) digital filters, and subsequently compare the two modified signals. One possible front panel and the block diagram are presented in **Figure 4**. The first strip chart shows the original temperature with time and the second chart displays the original temperature signal plus Gaussian white noise. The third chart shows a noisy temperature signal filtered by a Butterworth digital filter and the fourth one by a Bessel filter

[Oppenheim & Schafer, 1975]. The sequence of the signal processing is illustrated in the corresponding block diagram.

Liquid level control system

In this experiment, the students create a program to control either the fluid level in a fluid storage system or the gas pressure in a compressed gas storage system (the students may pick either one). For the purposes of the current paper, only the fluid level control system will be discussed in more detail. The fluid storage system consists of two tanks: Tank 1 (6" by 3') and Tank 2 (2.5" by 3'). The fluid level is controlled by a pneumatic control valve, and is measured in each tank with a Honeywell Smart pressure transmitter. Both transmitters for Tank 1 and Tank 2 operate with a 4-20 mA signal for a range of 0–50 inches of water. The control valves are operated by a 3–15 psig pneumatic pressure signal which is converted from a 4–20 mA signal by a pneumatic transducer (I/P). The Honeywell Smart flow transducer creates a signal of 4 – 20 mA for a flow range of 0 – 79 gph. A sample program is shown in **Figure 5**.

The control program calls for three icons: icons for the measurement of (1) flow rate, (2) level in Tank 1, and (3) level in Tank 2. Three common input variables to each icon are N (number for the For Loop), order of filter function, and sampling frequency. The outputs are filtered signals. **Figure 6** shows the details of the flow rate icon. The input to and output from the PID icon should be given as a percentage. The percentage is a dimensionless value within the upper and lower limits. The flow rate signal is normalized and placed between 13 and 14 in the strip chart. The set point, which is given in inches of water, is displayed in the strip chart. It is also converted into a percentage within the limits of the transducer signal range. The second input to the PID is the real-time level, which is measured by the T1 Level icon and converted into a percentage within the same limits. The third input determines either Automatic or Manual modes of controller operation. The last input is the control parameters: proportional gain, integral time constant, and derivative time constant. The first output of the PID icon is the controller output in percentage, so the next icon converts it to 4-20 mA current signal. This value is transduced to a 0-10 V signal prior to entering the AO 1 Point. The controller output signal is channeled through Device 1 and Channel 0. It is also plotted on the strip chart. The 3-15 psig signal actuating pneumatic control valve comes from it. One of the two typical tuning methods (Ziegler-Nichols and Cohen-Coon) [Stephanopoulos, 1984; Luyben, 1990] is shown in **Figure 7**. From the figure it can be extracted that the critical gain for the proportional controller is 400 or 0.25 in proportional band.

5. Conclusion

The approach of the course presented here is a distinctly modern departure from the conventional programming approach to data acquisition and control. The updated lab course caught the attention of the students from the first experiment. Students' year-end evaluations of the course over the last several years have consistently indicated that they find the course content informative and easy to understand, even the more sophisticated programs. Students also report that using LabVIEW graphic programming is helpful in creating flow charts. Although the

students initially found the sheer number of icons (over 800) somewhat overwhelming, the systematic structure of the icon presentation made this task turn out to be less daunting and, indeed, well within reach. By the end of the course, the vast majority of students are able to remember the icons they learned in the very first lab experiment they carried out. Perhaps most importantly, this course is able to effectively demonstrate the way in which discrete functions relate to real processes.

6. Recommendations

A graphical approach makes it easier for the students to understand the concepts of discrete functions and z-transform. The weekly lab reports are essential. The lab reports helped the students to integrate the lecture and lab experiments. Although it was expensive to implement all the hardware and software in a single year, the students' lab fees helped to alleviate initial funding problems.

7. Acknowledgments

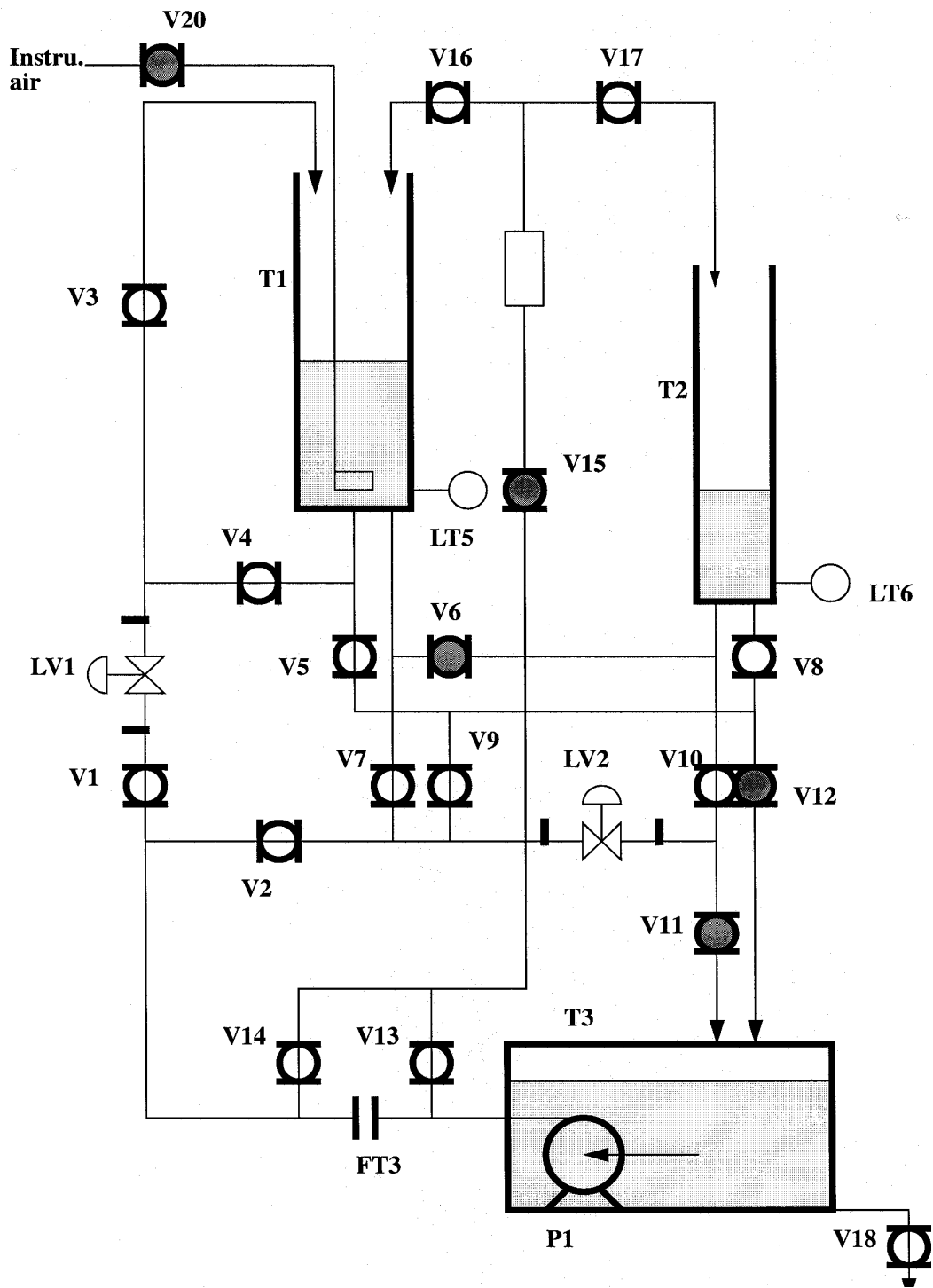
Professor Davis W. Hubbard (deceased) contributed in designing the initial draft of processes to be built. Dave Caspary, Lab Facilities Manager, provided the drawings and supervised the construction performed by our in-house master mechanic Dick Richards (retired). Edward Fisher, formerly Department Head, provided necessary resources.

Bibliography

1. Kim, Nam K. and Caspary, David, "Unit Operations Laboratory Experiments with a Total Distributed Control System," Proceedings of the 1993 World Conference of Scientists and Engineers, Section of Polymers, Materials, and Chemical Engineering, Seoul, Korea, pp 1378-1382, 1993.
2. Pintar, AJ, Caspary, DW, Co, TB, Fisher, ER, and Kim, NK, "Process Simulation and Control Center: An Automated Pilot Plant Laboratory," pp 145-150
3. Johnson, Gary W., LabVIEW Graphical Programming: Practical Applications in Instrumentation and Control, McGraw-Hill, 1993.
4. National Instruments: LabVIEW Analysis VI Reference Manual, Ch 4 Filter Vis, pp 5.1-55, 1996
5. Stephanopoulos, G, Chemical Process Control: An Introduction to Theory and Practice, Prentice-Hall, 1987.
6. Luyben, WL, Process Modeling, Simulation and Control for Chemical Engineers 2nd Ed., McGraw-Hill, 1990.
7. Oppenheim, Alan V. and Schafer, Ronald W., Digital Signal Processing, Prentice-Hall, 1975

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Nam Kim is an associate professor of chemical engineering at Michigan Technological University. He was involved in the design of the control system for the PSCC and advises student groups on the control aspects of the solvent recovery process and supervises other unit operations experiments. He teaches process control theory and process control laboratory courses at Michigan Tech. Kim does research in the area of advanced process control (adaptive and interacting multi-variables, statistical process control, fuzzy logic, and neural networks) and energy conservation and optimization. He has a Ph.D. from Montana State University in chemical engineering. (e-mail: kimnk@mtu.edu)



Figure

1. P & ID for the liquid level control system.



Figure 2. Digital picture of the water level control system.

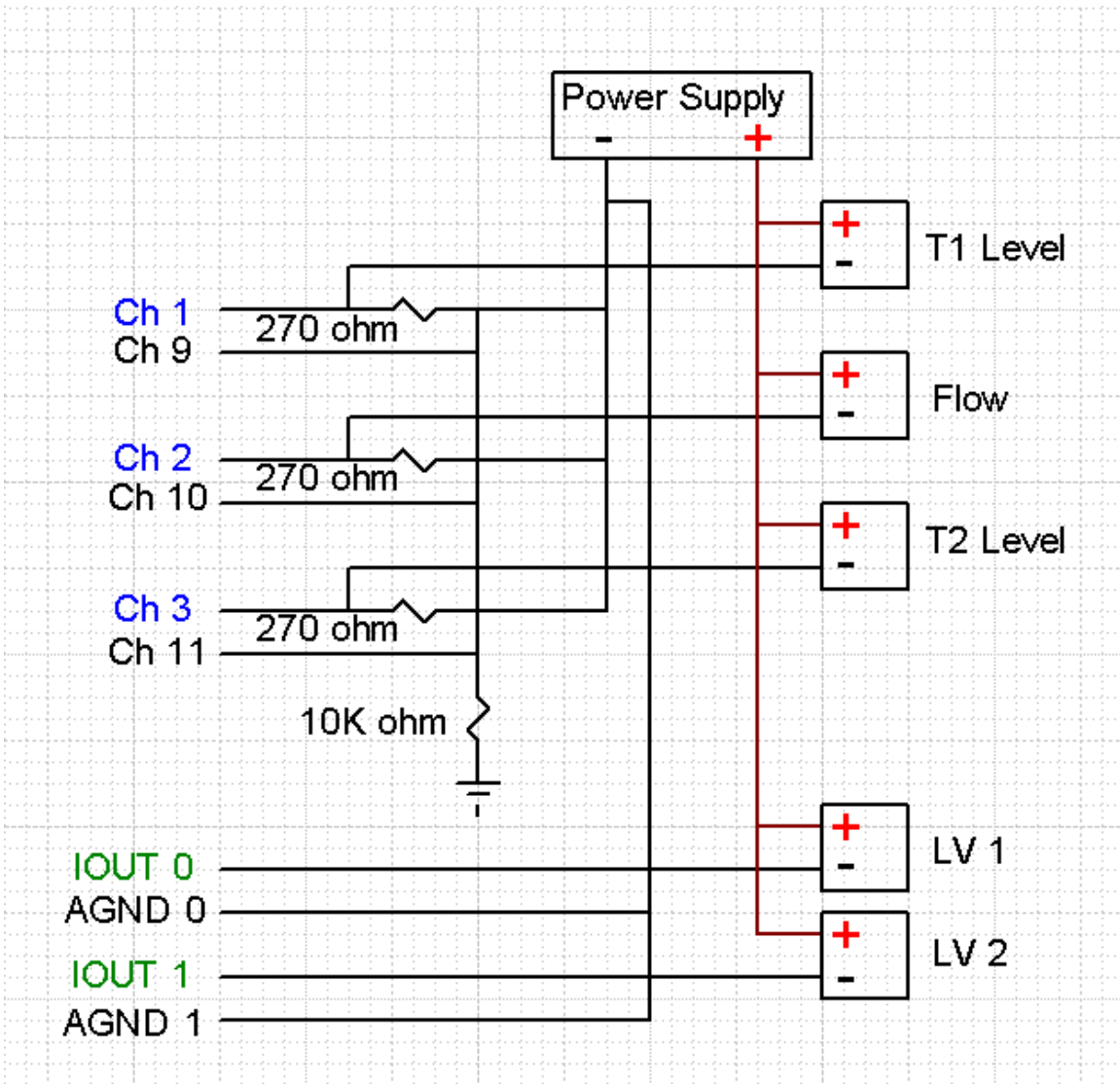
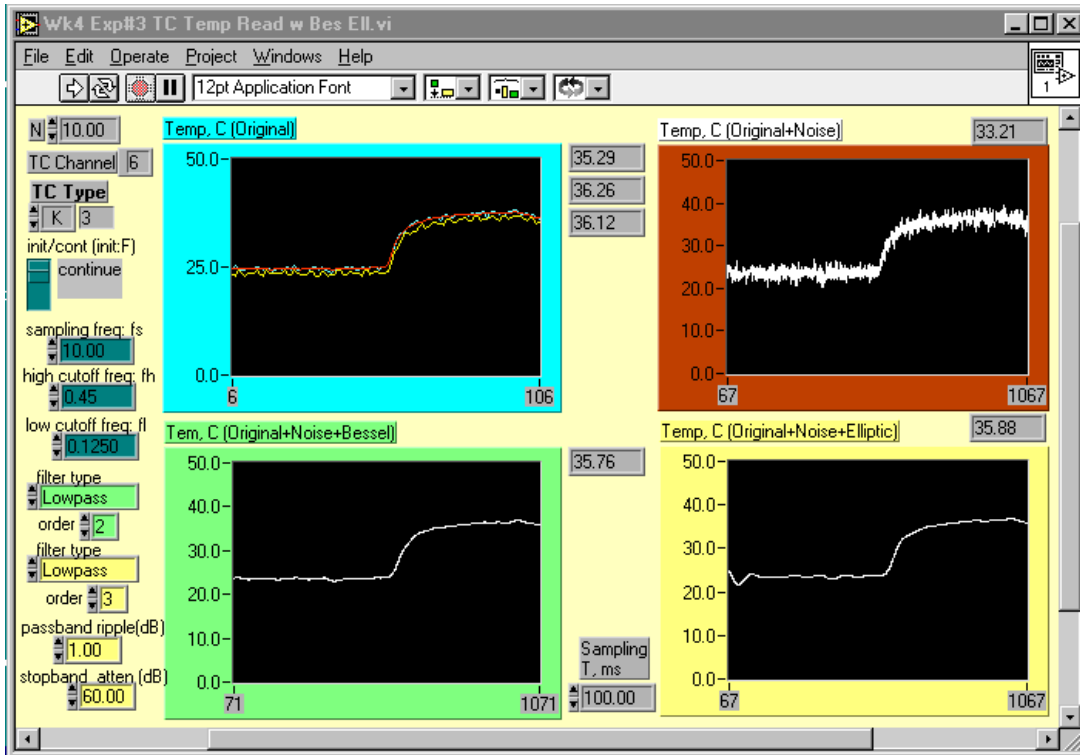
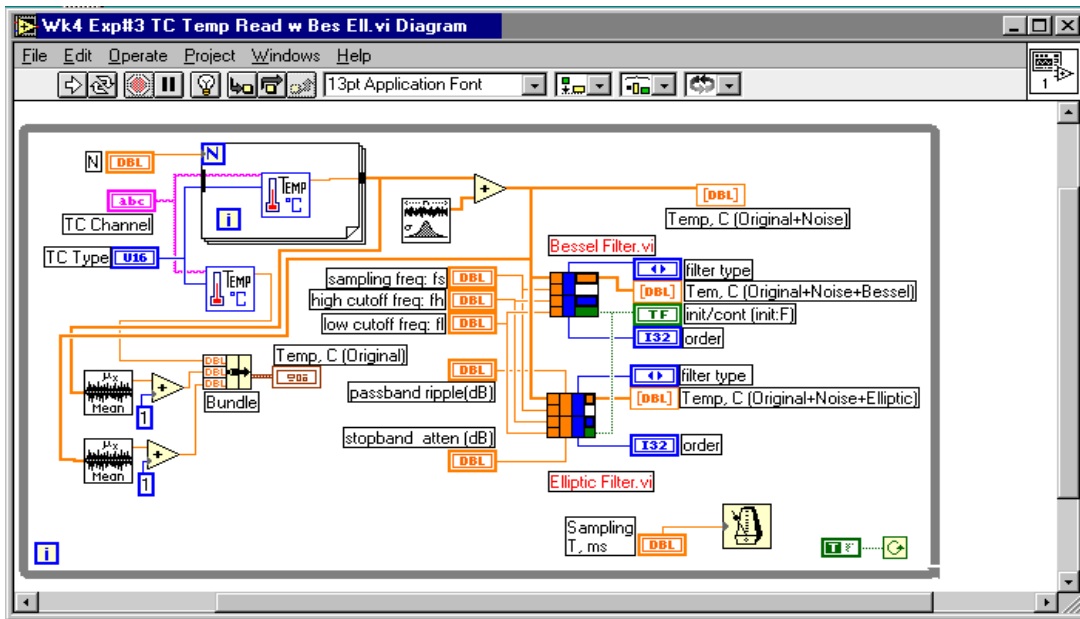


Figure 3. Wiring diagram for the power source

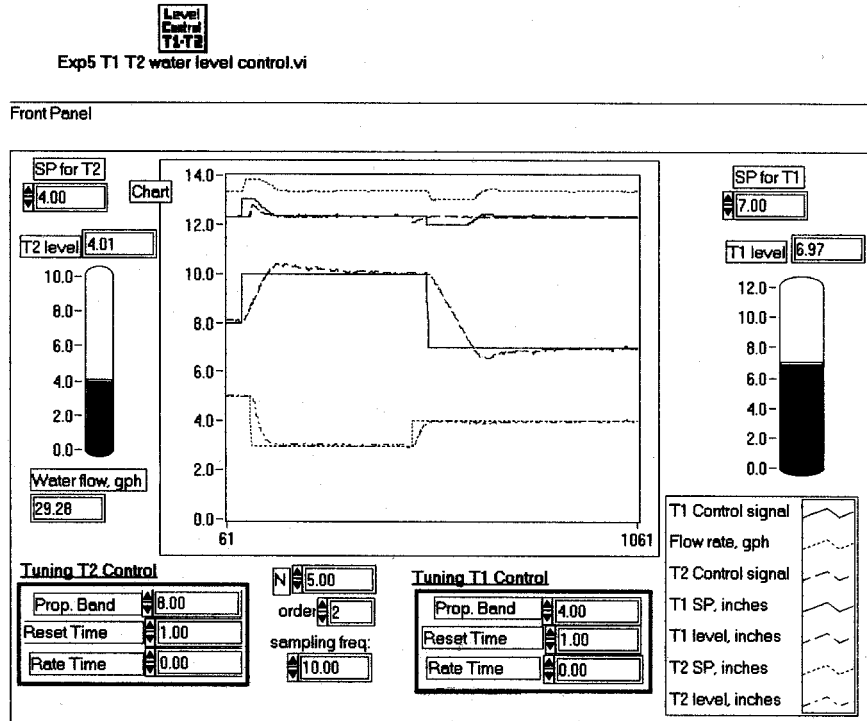


(a)

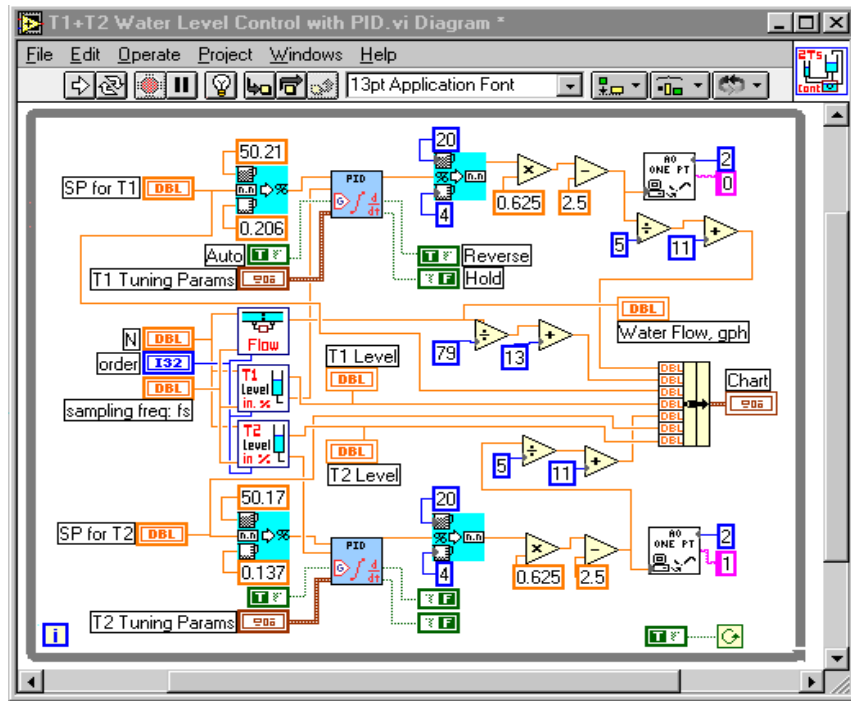


(b)

Figure 4. Front panel for the virtual instrument:
 (a) noisy data and performance of digital filters and (b) block diagram.



(a)



(b)

Figure 5. Level control for a series of two tanks: (a) front panel and (b) block diagram.

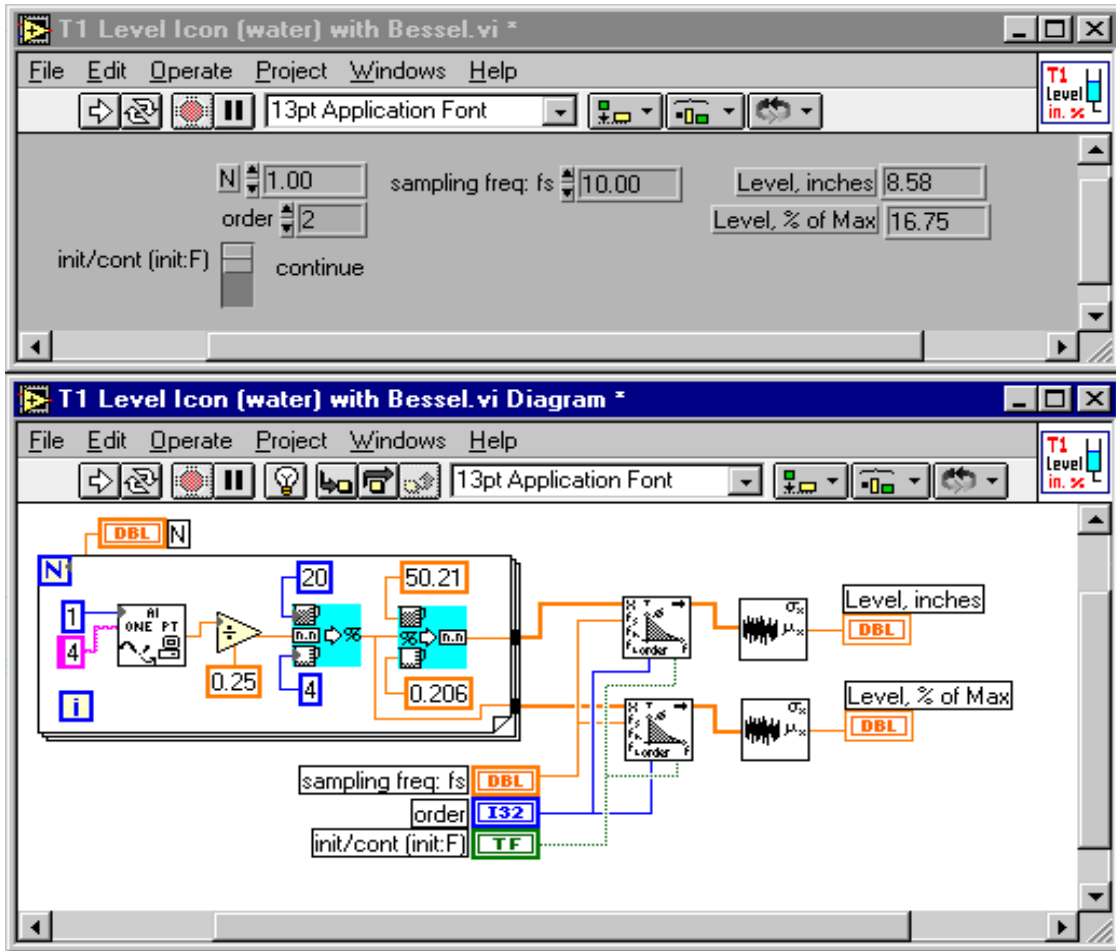


Figure 6. Data acquisition of filtered tank level signal.

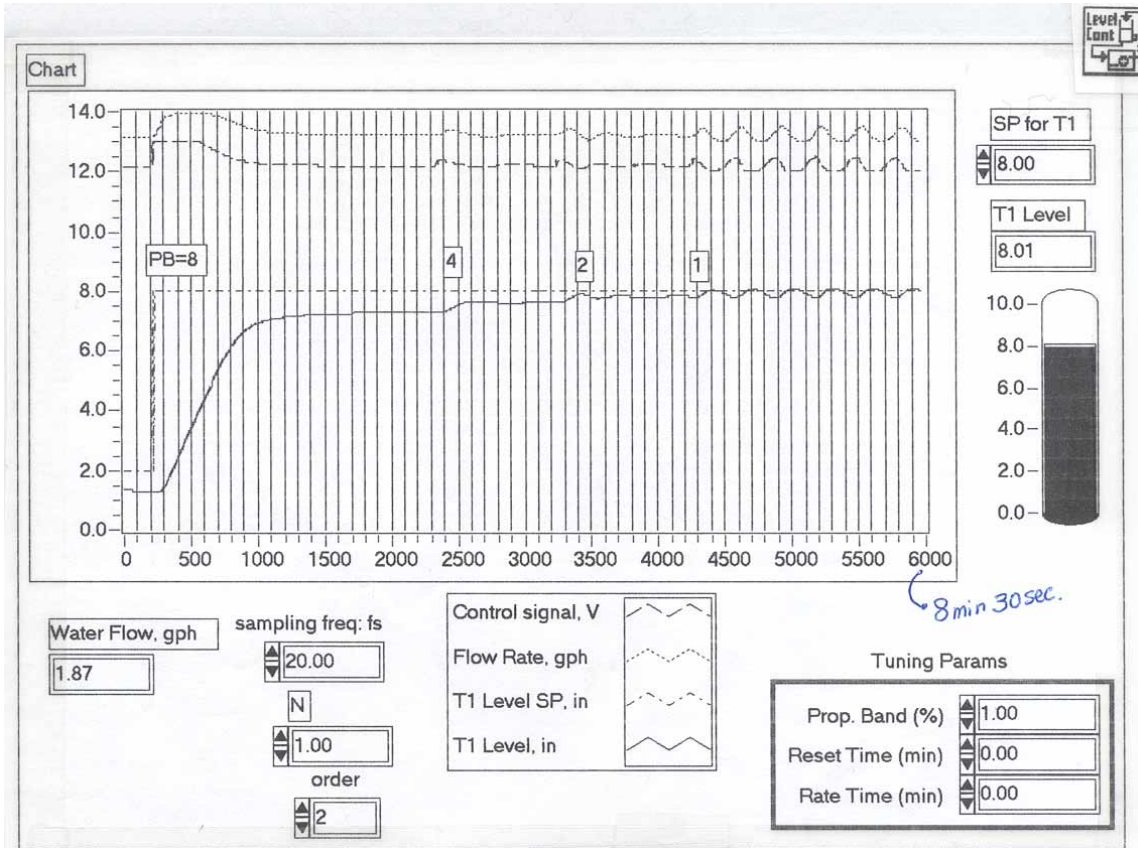


Figure 7. Real-time data for Ziegler-Nichols tuning.