Modernizing a Physical Measurements Laboratory in Engineering Technology

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Abstract

In 1997, the Mechanical Engineering Technology faculty at Youngstown State University were awarded a National Science Foundation Instrumentation and Laboratory Improvement Grant to modernize a Physical Measurements laboratory, NSF-ILI Grant # DUE-9750992. This paper details the experience of that project.

The objectives of the project were: to greatly increase the number of sensors available for student use in the laboratory; to introduce modern Computer Data Acquisition equipment and techniques; and to shift the course emphasis as much as possible from lecture to laboratory, using the strengths of interdisciplinary teams of students (MET and EET) to aid in learning.

Equipment was purchased, and nine experiments were designed or revised to investigate the behavior of over thirty sensors and sensing systems, as detailed below.

Several experiments use National Instruments data acquisition hardware and its LabVIEW software, including custom Virtual Instruments. However, the course is not intended to teach LabVIEW programming. Instead, these tools are used to aid efficient progress through experiments, and to provide real-time graphic displays of sensor and circuit performance.

This paper details the lab development, describes the equipment used, describes the use of LabVIEW in this course, and gives feedback on the project and the experience of modernizing the laboratory.

Introduction

The Mechanical Engineering Technology program at Youngstown State University is a TAC/ABET accredited program with an enrollment of approximately 100 to 120 majors. There are two full service faculty, and a pool of approximately seven part-time faculty who teach approximately half the courses offered. Despite the demise of Youngstown's steel industry, the Youngstown area is home to many manufacturing enterprises. These companies provide employment for the great majority of YSU's MET graduates.

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The junior year of the MET program includes Physical Measurements, a required course for Mechanical and Electrical Engineering Technology majors. The course is a survey of the sensors and measurement systems for various quantities such as dimensions of mechanical parts, strain, pressure, temperature, and fluid flow. The course also covers such fundamental topics as standards of measurement, statistical treatment of data and pertinent electrical circuits.

Sensors are an integral part of modern manufacturing, and sensing and measuring techniques have become even more important as manufacturing has become more automated. In recent years, the use of computer data acquisition has revolutionized measurement technology. With these facts in mind, the faculty of YSU's MET program sought to modernize the Physical Measurements course and laboratory.

With the help of the MET Industrial Advisory Committee, several new experiments were proposed, and vendors were tentatively identified for new equipment. In a grant application to the National Science Foundation, the faculty described the desire to greatly increase the number of sensors available for student use in the laboratory; to introduce computer data acquisition; and to shift as much as possible from lecture to hands-on, laboratory-based learning. The grant application was successful, and after being awarded NSF/ILI grant # DUE- 9750992, the faculty assumed the challenge of purchasing equipment, learning its operation, designing experiments, and restructuring the course.

Data Acquisition (DAQ)

A major addition to the Physical Measurements laboratory was to be the use of computer data acquisition, or DAQ. The MET faculty chose National Instruments' hardware and their LabVIEW software for data acquisition. National Instruments is a market leader in this technology, with a well-integrated package of software and DAQ hardware. National Instruments personnel conducted two seminars at YSU that showcased their products, and faculty from many programs were impressed with the capability of the hardware and software.

Early in the project, it was decided that teaching LabVIEW programming would not be an objective of the course. Since LabVIEW is a unique graphical programming environment, learning LabVIEW programming would be as complex as learning Visual Basic or C++, and would require an entire course dedicated to that subject alone. Instead, LabVIEW and DAQ would be used as tools to increase the efficiency of the exercises in the Physical Measurements laboratory. Students would make use of LabVIEW programs or "Virtual Instruments" (VIs) custom-written for their labs. These VIs would acquire data during the experiment and produce real-time graphs of the output, enabling students to observe the relationships between experimental variables as the experiment progressed. In addition, the VIs would stream data to disk for further analysis by spreadsheet software, to be used as part of the students' lab report. Thus, the students would be introduced to the capabilities of LabVIEW and DAQ.

This approach presented challenges to the faculty. Use of preprogramed VIs supplied with

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LabVIEW can be very easy, but construction of custom VIs is much more complicated.[1] Furthermore, a series of events added greatly to the difficulty of the entire project: one MET faculty member left YSU, temporarily leaving only one full-time faculty member on staff; preparation for a TAC/ABET visit began; and YSU's administration mandated changing the university's calendar from quarters to semesters, requiring complete overhaul of all curricula.

Fortunately, a YSU student in a co-op position had become expert at LabVIEW programming. This student volunteered to help construct custom VIs for the Physical Measurements laboratory. His efforts were successful, and several useful custom VIs are now being used in this lab.

The experiments

The first two experiments in the Physical Measurements course consist of explorations of electrical circuit performance using LabVIEW VIs, and exist in seven copies for simultaneous running by the entire class. Subsequent experiments exist in one copy each, and the lab groups perform these on a rotating basis. Descriptions of the experiments follow:

Signal Conditioning Circuits: Sensitivity and Linearity. The first experiment examines the performance (especially linearity and sensitivity) of the simple current sensitive circuit, the ballast circuit, the Wheatstone bridge, and the constant current circuit, as used with resistive sensors. Circuit boards were constructed containing five identical linear variable resistors, a multi-turn rheostat, and several fixed resistors. These allow students to quickly wire the various circuits, with the variable resistors representing sensors. As a resistor's slider position (hence resistance) is changed, the circuit's output voltage is recorded, and the voltage *vs.* position data used to evaluate the circuit's performance. In addition, students explore the design and performance of an automotive fuel gage sending unit which operates on similar principles. A LabVIEW VI allows rapid collection of voltage-vs-position data, displays a real-time graph of the same data on the VI's front panel, and stores the data for later spreadsheet use.

Laboratory power supplies provide voltage inputs. The constant current circuit uses a National Instruments SC-2042 interface board as the current source. While this is a somewhat complicated and specialized piece of hardware, it greatly simplifies the interfacing of resistive sensors.

Signal Conditioning Circuits: Filters and Spectrum Analysis. Additional circuit boards were constructed featuring five simple filter circuits: passive low pass, passive high pass, active low pass, active high pass, and active notch filters. The objective is not to examine filter design in detail, but to examine fundamentals of filter performance by generating modified Bode plots (output voltage vs. frequency). Students manually record data for one filter, with aid of a function generator and oscilloscope. Next, they use a custom VI to repeat that run much more quickly, and to test all other filters. Data is stored for later processing by spreadsheet software.

The VI for this experiment uses the analog output capability of the DAQ card to generate

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sinewave outputs that become inputs to the filter circuits. Filter outputs are acquired, plotted and streamed to disk. Real-time on-screen plots of the results are generated as the frequency of the output is varied automatically. Students also examine the effects of generating an analog output from a digital device, especially the limits of resolution, and are introduced to concepts such as the Nyquist Frequency and aliasing.

A second phase of this experiment uses a LabVIEW-supplied VI to perform spectrum analysis of various waveforms. A signal generator's output is fed to the DAQ card, with and without the use of filter circuits. This allows students to see the effects of filters in the frequency domain as well as in the time domain, and introduces students to the LabVIEW library of customizable preprogramed VIs.

Temperature Measurement. Students are introduced to the characteristics of a thermocouple, thermistor and resistance temperature detector (RTD) in this experiment, again by use of a custom VI. A DAQ card is used to acquire voltage from the thermocouple and resistance from the thermistor and RTD as these sensors are heated in an electric "hot pot" containing water. Voltage and resistance variations versus time are displayed on a real-time graph generated in LabVIEW, so students can observe the difference in sensitivity and linearity of the sensors. Simultaneously, the raw data is converted to temperature readings by LabVIEW and graphed as three curves on a temperature vs. time graph. Students examine the LabVIEW program (or "diagram") to identify the computational techniques that convert the electrical parameters to temperature measurements. Finally, the system acquires data while the sensors are subjected to a step change in temperature (from freezing to boiling), to evaluate the time constant of the system. Again, all data is streamed to disk for further processing by the students for their lab reports.

Strain Gage Fundamentals. This experiment combines instruction on the fundamental performance of strain gages with an examination of propagation of uncertainty. An aluminum cantilever beam is deflected by a micrometer head, and a commercial strain indicator from Vishay Measurements Group is used to measure the output of a strain gage. Students compute theoretical strain, based on their measurement of beam dimensions and deflection, using elementary principles of mechanics. In addition, they estimate the uncertainty in each of their measurements, and use calculus-based propagation of uncertainty principles to compute the expected uncertainty in strain measurement. The measured strain is compared with the theoretical strain, and any differences are compared with the expected uncertainty.

Strain Gage Bridges. Whereas the previous experiment makes use of a single strain gage, the Strain Gage Bridges uses similar techniques with multiple strain gages. The objective is to examine techniques for increasing output sensitivity and providing temperature compensation. Using equipment purchased from TecQuipment Inc., students deflect a double cantilever beam fitted with multiple strain gages, and examine the voltage *vs.* position output of quarter bridge, half bridge and full bridge circuits. The beam is electrically heated to demonstrate temperature compensation effects. In addition, semiconductor strain gages are compared with ordinary foil

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strain gages in regard to sensitivity to strain and to temperature.

*Area Measurement Using Planimeter*s. While planimeters are used much less today than they once were, these simple mechanical devices have certain advantages, and demonstrate that not all measurements must involve electronics. However, the primary reason for inclusion in this lab is that operation of a planimeter naturally induces random error, due to manually tracing the outline of the area to be measured. This random error is statistically processed by the students to examine the effects of sample size on mean, standard deviation, and confidence intervals of measurements.

Fluid Flow Measurements. A Leybold tabletop wind tunnel was purchased through the grant, and is used with a variety of flow and pressure sensors. Students perform measurements of flow velocity in the throat of the wind tunnel using both a hotwire anemometer and a small turbine meter by Solomat, then perform a velocity survey of the throat. Total volume of flow is computed, and correlated with flow measurements taken by means of a venturi meter, an orifice meter, and a Pitot-static tube. Students measure pressure differentials using U-tube and inclined manometers, and observe the "loading" or restriction effects of the various meters.

Machinist Measuring Tools. This experiment consists of a variety of mechanical parts and a wide selection of micrometers, vernier calipers, dial indicators, gage blocks, etc. Students learn the use of these traditional tools by following instructions and viewing photographs in the lab handout, and confirm their understanding by measuring the mechanical parts. Feedback is provided immediately, so measurements can be repeated if necessary until correct readings are obtained.

Industrial Proximity Sensors. The MET program was the recipient of a generous gift of approximately 50 different industrial optical and proximity sensors, with full documentation, by Ken Kling of MC^2 Corporation. This allows the inclusion of an additional, less structured experiment in the course. Each team of students is given their choice of a sensor from those available. They then research the sensor's performance characteristics, determine an example of a practical industrial application for the sensor, and do a class presentation on their findings.

Experiment Design, and Team Philosophy

The design of the above experiments differs from most experiments in YSU's MET courses. Typically, experiments are intended to reinforce topics recently covered in course lectures. Thus, background concepts generally need little review, and experiment handouts deal primarily with operation of equipment. Data is generated which is used to verify expected results.

This Physical Measurements course generally follows a different model. Since most experiments require rather expensive and specialized equipment, it is not cost effective to have multiple stations. However, the nature of the equipment mandates small lab groups. Therefore, each team rotates through these one-station experiments, and each lab period has six different

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teams simultaneously performing six different experiments. Obviously, many of these involve devices and techniques that have not been covered in detail during class lectures.

These equipment limitations, and the desire to shift emphasis from the lecture to the lab, motivated the MET faculty to use a different style when writing experiment instructions. The Physical Measurements lab handouts are written to explain many of the fundamentals of the sensors or sensor systems. Thus, much learning of these fundamentals takes place during lab preparation time and actual lab time, rather than during the lecture.

Students are urged to study the appropriate portions of the lab handouts before the lab period (and in some cases, given pre-tests on the reading material as added incentive). Furthermore, lab directions require that students make observations and answer brief questions as the lab progresses. This process is part of the learning experience, and these answers become part of part of the students' final lab report.

As stated, the Physical Measurements course is taken by students in both the Mechanical Engineering Technology and the Electrical Engineering Technology programs. Since this laboratory makes extensive use of both mechanical and electrical skills, lab teams are chosen so that each team has representation from both majors. Thus, when electrical skills or observations are required, the EET majors are expected to use their strengths to aid the MET students' understanding, and vice-versa. This approach seems to work well. Much student-to-student instruction takes place, with the instructor circulating between groups to give additional direction as needed.

Future Enhancements

Development work on this course and laboratory is still very much in progress. Enhancements are planned for several existing experiments, and other experiments are expected to be added in the future.

One major addition now being constructed is an experiment involving a comparison of various pressure sensors. A pressure testing bench has been purchased from Hampden Engineering, featuring a reciprocating compressor and a selection of manometers, gages and electronic pressure sensors. Plans call for an experiment that uses manual readings to investigate the linearity, sensitivity and calibration of sensors suitable for static pressure readings. Also, a LabVIEW VI will be used to investigate the dynamic characteristics of two electronic sensors of different design, when subjected to cyclic pressure variations and step changes in pressure.

A second experiment to be added involves correlation of an accelerometer with an LVDT position sensor. The two instruments will be mounted on a slider block and moved quickly by hand. A custom LabVIEW VI will be programmed to acquire acceleration and position data. The VI will double-integrate the acceleration data and compare the results with the position data.

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A third planned addition is the exploration of various rotary position sensors. Students will examine the technology and performance characteristics of resolvers, and incremental and absolute optical encoders of various designs.

Other enhancements are planned for the experiments already in use, described above. For example, after observing several classes, possible improvements to the "front panels" or operator interfaces of the VIs have been noted.

The mechanism of providing instantaneous feedback to students in the Machinist Measuring Tools experiment is still changing. At one time, feedback was given immediately *via* custom software written in Pascal. Due to recent changes in the experiment, this program needs revision, and must be ported to a more current programming environment, either LabVIEW or Visual Basic.

Other minor changes to various experiments are planned, as are improvements to documentation for faculty, as described below.

Project Evaluation and Recommendations

When considering the balance of benefits and detriments, has the considerable effort expended in this lab been worthwhile? Should others consider similar efforts? What should have been done differently?

There is little doubt that the Physical Measurements course and laboratory have been greatly improved, and continue to improve, as a result of this NSF/ILI grant. Student satisfaction has been high, as evidenced by in-class comments and responses to surveys. Students now gain hands-on experience with more than 30 sensors or measurement systems, and become acquainted with very up-to-date measurement technologies. This improvement in laboratory content, and in the resulting learning experience, has been gratifying.

The concept of multi-disciplinary student teams learning by hands-on lab techniques appears to work well. Students interact very enthusiastically within the lab teams, and seem very much engaged in the experimental experience. However, one shortcoming of this lab's structure is that the learning is more time consuming. When students are required to read, understand and answer questions during the experiment's progression, much more lab time is required. Several experiments are longer than preferred. Nonetheless, it is felt that this approach has sufficient value that it should be retained.

A separate question is the wisdom of applying for a large grant and overhauling the lab completely in one massive project, as opposed to another possible approach - that of step-by-step improvement over a longer period of time. An obvious advantage of the approach taken at YSU is that mechanisms such as NSF grants exist for acquiring outside funds for significant projects. Such funds may be more difficult to acquire, or at least require more creativity, if a

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step-by-step approach is used.

In our case, the large project approach did present certain difficulties. Technical difficulties did occur in the form of equipment failures and programming problems - but technical difficulties will always occur. One obvious piece of advice for those contemplating similar projects is to be very generous in estimates of staff requirements and completion time. If possible, grant applications should include funds for salary replacement, to ensure that grant development does not overburden faculty already fully engaged in other duties.

Programs with small numbers of full-time faculty should proceed with great caution before embarking similar large-scale projects, and be sure to learn of any major administrative projects on the horizon. A project of this magnitude should not be attempted during a major institutional change such as a quarter-to-semester transition.

Programs with small numbers of faculty should also give consideration to program stability and technical depth, especially before introducing complicated custom systems. To elaborate: in any technical laboratory, there will be equipment whose operation must be learned by the faculty in charge. Normally, manufacturer’s manuals provide adequate information, and troubleshooting is reasonably straightforward. However, when laboratory equipment involves custom hardware, modern computers and custom software, learning lab procedures becomes much more difficult for potential faculty. Troubleshooting, in particular, can be very difficult.

In programs that rely heavily on part-time faculty, this becomes more problematic, since turnover of part-time faculty is much more rapid, and the technical complexity can greatly reduce the pool of faculty that are competent to teach the course. Furthermore, in the event of sabbaticals or other changes in personnel, even full-time faculty can find themselves in extremely challenging circumstances.

One solution is documentation. The author hopes to write a detailed lab manual for faculty (both full-time and part-time) who will be assuming responsibility for this lab. The manual will include tips on troubleshooting, and space for a log of problems and solutions encountered. The hope is that the faculty lab manual will be a growing document, and aid those who assume responsibility for the lab.

Regarding documentation, it should be noted that LabVIEW VIs are programmed graphically by drawing a flowchart-like "diagram". While this programming approach has certain advantages, it makes the details of VI operation somewhat difficult to document. It may seem that this is a problem only during development - that once VIs have been proven and have reached their final configuration, the details of operation are unimportant. Still, further changes may become desirable at future dates, perhaps after the original programmer is no longer with the institution. Thus, it is prudent to take steps to document in detail the operation of any custom software.

Finally, in any project involving custom software, it is beneficial to employ "beta testers" that

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will have skill sets identical to the end users. In the case of the custom VIs employed in this lab, the faculty and student lab assistants who tested the software were perhaps too close to the project. Students who ultimately used the VIs exhibited uncertainty regarding certain aspects of the operation, which might have been alleviated by improvements to the "front panels" of the VIs. It would have been beneficial to learn this while the VIs were undergoing initial development.

Conclusion

The modernization of the Physical Measurements laboratory at Youngstown State University has been successful. Students become acquainted with a wide variety of measurement tools and techniques, including computer data acquisition. Use of computer data acquisition has been beneficial, has shown that custom data acquisition programs can increase the efficiency of laboratory exercises and guide student learning. However, in a laboratory which makes use of such varied hardware and custom software, care must be taken to provide adequate documentation for future faculty members.

Acknowledgments

The modernization of YSU's Physical Measurements Lab would not have been possible without much help and support.

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Dr. Mansour Zenouzi, formerly of YSU, was instrumental in developing the concepts of the experiments and in writing the original grant.

The members of the MET Industrial Advisory Committee all contributed to the design of the lab, but Advisory Committee member Ted Burke, PE, of Ajax Magnethermic Corporation was a special asset from the start. Ted taught the course as a part-time faculty member during the transition, and helped greatly in the design of the experiments. He brought invaluable industrial experience to the project.

Ken Kling of MC^2 Corporation deserves thanks for his very generous donation of industrial sensors and catalogs, as well as for his in-class presentation on sensor technology.

Thanh Vo provided eager assistance and tremendous expertise in LabVIEW programming. Without his help, the VIs used in the lab would be much less capable.

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Finally, the dedication and skill of Scott Buckner, EIT, as a lab assistant were outstanding. Scott's contributions went well beyond the call of duty, and his wide-ranging knowledge of technology and practical techniques were absolutely invaluable in this project.

Few things are as satisfying to an educator as having dedicated students who have risen to the level of competent professionals and colleagues. Thanks again to Thanh and Scott.

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