AC 2010-984: INSTRUMENTATION EMPHASIS IN UNDERGRADUATE MECHANICAL ENGINEERING PROGRAMS

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Instrumentation Emphasis in Undergraduate Mechanical Engineering Programs.

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Abstract

This paper reports the results of the development and implementation of hands-on laboratory experiments in a newly developed laboratory for a two-semester undergraduate course in Instrumentation and Measurements in Mechanical Engineering. The course, designed for the undergraduate junior level, was a two-semester course for a total of four credits, and it took place in conjunction with a one-hour classroom lecture in mechanical engineering. A modified version of this approach, however, can easily be used at all levels of the mechanical engineering curriculum. An important component to the process involves the utilization of a two-semester long, open-ended project (OEP) that required the students to come up with creative approaches to problem solving. Over the course of the year, a full-cycle learning experience took place. After acquiring the necessary minimum knowledge, the students began their OEP by developing an initial idea. They then went on to design and construct a working prototype (that included both system and measurement sensors on prototyping boards), and concluded the project by conducting a feasibility study by writing a report and delivering a class presentation. Because the ELVIS system has been used primarily as an instructional tool in electrical engineering laboratories, an extensive process that adapted it to the needs of mechanical engineering was implemented. This included the development of completely new experiments that involved newly-designed hardware and instructions that were all developed and built in-house with student participation.

Topics: laboratories and experiments; innovative experiments; instrumentation emphasis in undergraduate programs.

Introduction

During the undergraduate teaching process, instructors and students often get bored solving simple textbook problems that require little, if any, imaginative thinking. These types of problems are usually significantly simple compared to real life situations, and more often than not, they have very limited connections to the real world. They are also very limited in terms of their usefulness in incorporating the individuality of the students involved, and they make it difficult to give students genuine, individualized feedback about their control of the process. All of these qualities diminish the overall efficiency of the students' learning during the lab process. It is recognized that an efficient learning process always requires excitement, creativity and close interaction with the subject matter. Hands-on physical experimentation is one of the best solutions to fulfill these requirements. In order to increase student interest and the student's own creative, hands-on problem solving skills, a unique and innovative sets of physical experiments has been developed and implemented which pushes students' creativity to its limits by applying combinations of both a set of controlled experiments and open-ended projects that formulate and investigate realistic, inventive, and complex problems. An approach like this not only boosts student enthusiasm, but also aligns classroom topics more closely with contemporary industrial issues increasing students' ability to be successful in their future professional life .

Although theoretical and computational tools (including virtual tools) are useful in the teaching of engineering processes, it is generally accepted that physical experimental approaches are far superior, even though they are oftentimes more costly and time consuming. In many cases, experiments are necessary when attempting to prove a hypothesis and turn it into a theory. Physical experiments are also necessary when trying to implement a proof-of-the-concept process or during live tests for a new product or technology. Consequently, it is important for mechanical engineering students to conduct physical experiments so that they have hands-on experience with the types of tools used in instrumentation and measurement. By doing these activities, students can gain knowledge about issues such as what measurements to use, how to develop a feasibility study program, how to conduct computer-based data acquisition and analysis processes, how to validate experimental data for both deterministic and random processes, how to design experiments, how to apply both statistical and deterministic tools for data analysis, and how to disseminate results.

There are many obstacles, however, to accomplishing a comprehensive process like this, especially with the reality of today's classroom, where virtual reality approaches, even though they cannot fully replicate physical experiments, have become so common. The most common hurdles in this process are the amount of time it takes and the cost of the development of a laboratory and shop base. Time and money are absolutely necessary for the constant troubleshooting process, but they create a large financial burden as well as a tremendous increase in the teacher's responsibilities compared to the demands of a standard lecture or virtual laboratory class. Oftentimes, obstacles like these force engineering educators to make compromises and replace physical laboratory experiments with virtual experiments, which are often performed as blackboard exercises in a lecture classroom. One way to reduce the cost is by implementing physical experiments on miniature mechanical systems, building prototyping sensors and measurement systems from "scratch" as a part of the laboratory experiments. Additional cost reduction can also be provided by utilizing scaled-up models and electronic databases available on the Internet and using inexpensive, computer-aided experimentation systems. All of these approaches are extremely attractive in today's "lean" approach to engineering education.

The course presented here was designed for an undergraduate junior level class that took place over two semesters for four credits and was done in conjunction with a one-hour classroom lecture in mechanical engineering. A slightly modified version of this approach could easily be tailored to all levels of the mechanical engineering programs, as well as to other engineering programs.

This particular laboratory's development process began by writing a successful proposal for outside funding in order to create a hands-on physical experimentation laboratory. After the laboratory was established, the next step involved developing and conducting instructed experiments in which a key issue was to find a challenging phenomenon related to mechanical engineering with a high potential for further development and exploration beyond the Instrumentation and Measurements class – not closed ended only experiment. One of the most challenging issues in fluid mechanics is two-phase flow. This offers a plethora of opportunities for students and has a high potential for experimental exploration involving a majority of instruments, systems and methods used in the Mechanical Engineering profession. Students start by performing controlled experiments and after learning basics instrumentation and measurements tools (including computer-aided measurement systems and sensors), and developing their hands-on experience with deterministic and statistical tools, they continue the learning process by scaling down and modifying a two-phase flow system as their open-ended project (OEP). After building a working prototype (with completed computer-aided measurement systems with sensors) and conducting a feasibility study, the students analyze and present the data in oral presentation and written report.

This paper reports the results of the development and implementation of hands-on laboratory experiments in a newly developed laboratory for a two-semester undergraduate course in Instrumentation and Measurements in Mechanical Engineering. The course, designed for the undergraduate junior level, was a two-semester course for four credits, and it took place in conjunction with a one-hour classroom lecture in mechanical engineering. A modified version of this approach, however, can easily be used at all levels of the mechanical engineering curriculum. An important component to the process involves the utilization of a two-semester long, open-ended project (OEP) that required the students to come up with creative approaches to problem solving. Over the course of the year, a full-cycle learning experience took place. After acquiring the necessary minimum knowledge, the students began their OEP by developing an initial idea. They then went on to design and construct a working prototype (that included both system and measurement sensors on prototyping boards), and concluded the project by conducting a feasibility study by writing a report and delivering a class presentation. Because the ELVIS system has been used primarily as an instructional tool in electrical engineering laboratories, an extensive process that adapted it to the needs of mechanical engineering was implemented. This included the development of completely new experiments that involved newly-designed hardware and instructions that were all developed and built in-house with student participation.

Educational Laboratory

There are three basic types of engineering laboratories where physical experiments are conducted—educational, developmental, and research-focused.[1] This paper deals with an educational laboratory in Instrumentation and Measurements for mechanical engineering students. In this particular class, the students received their first serious exposure to the physical experiments, experimentation, and lab tools that are used in engineering. In this class, the students needed to learn and be able to apply the basics of computer-aided experimentation, instrumentation and measurements, experimentation and data collection, data analysis and presentation, and sensors and transducers that have applications for deterministic and random processes.

The course, designed for the undergraduate junior level, was a two-semester course for a total of four credit hours. It was conducted as a three-hour laboratory in conjunction with a one-hour weekly classroom lecture in mechanical engineering. Previously, the course used the same format, but the laboratory activities were demonstrative instead of hands-on, and the application of computer-aided measurement systems was limited. In accordance with the ABET accreditation process, the university recognized an urgent need to develop a computerized, state-of-the-art, hands-on instrumentation and measurements laboratory for these classes.

The development process of the new laboratory proceeded according to five main criteria: (1) the creation of a hands-on approach that would increase student interest and knowledge, (2) the use of computer-aided experimentation, (3) affordability, (4) the use of available resources, and (5) obtaining external financial support. The first decision involved choosing a computer-aided measurement system with sensor and transducer sets. After performing a market analysis and looking at each system's affordability and potential as a learning tool for students, we chose to concentrate the lab activities around the use of an inexpensive, computer-aided experimentation system like NI ELVIS. This system uses prototyping boards for the building of sensors and

Figure 1: Custom Made Statistical Columns for Experimental Apparatus (top), Partial View of the Laboratory (bottom).

Figure 2: Experimental Station. Custom Made Statistical Column for Experimental Apparatus (left), ELVIS Benchtop Workstation with Circuitry on Prototyping Board (left bottom), and Observation of Flow Patterns in Statistical Column (right top).

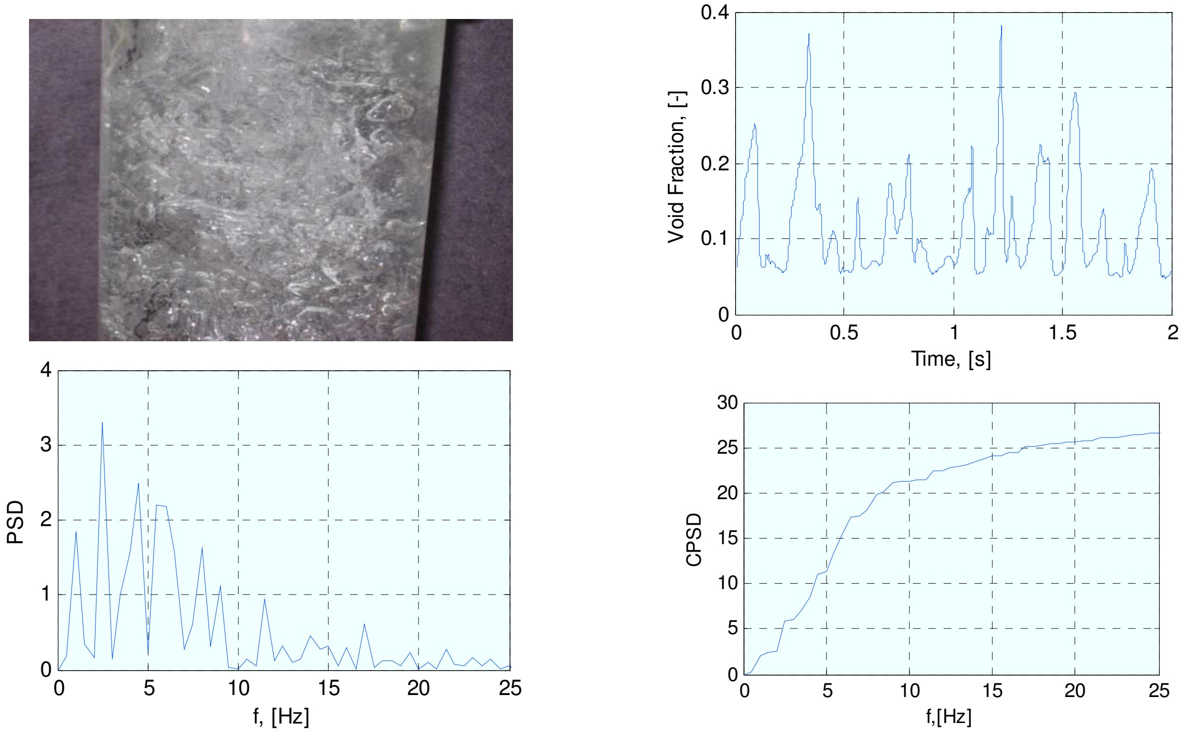

Figure 3: Column with a Churn Flow (top left), Void Fraction vs. Time Signal from the Column (top right), Power Spectral Density (PSD) of the Signal (bottom left), and the CPSD (bottom right).

Figure 4: Concomitant Measurement Systems for the Final Experiments with Data Validations in an OEP.

transducers which the students were able to create from basic electronic elements according to a unique design. A statistical column had also been previously developed and designed by the author[4,5,6,7] and it was built in the department's mechanical shop (see Fig. 1). This hardware was a substantial element in the creation of the experimental station (see Fig. 2). For the laboratory class, two major activities were designed and developed: (1) a series of structured experiments, and (2) an open-ended project (OEP). Both activities were designed in such way that the students would gain hands-on experience with sensors and measurement systems. They were also designed so the students could learn and aply; (1) data analysis with a computer-aided experimentation system for applying statistical analysis, (2) data validation using concomitant systems, (3) the design of experiments, (4) the prototyping of systems, (5) scaling-up modeling, and (6) the use of electronic databases from the Internet.

Together, the bench-top workstation and the Computer-Aided Data Acquisition System (CADAS) with the statistical column created a comprehensive and universal laboratory tool that can be used for most structured experiments, including those that involve OEP systems. Via the front control panel, the workstation provides convenient connectivity and functionality (in the form of BNC and banana-style connectors to the NI ELVIS) with the function generator and variable power supplies. The ELVIS software routes the signals in the NI ELVIS bench-top workstation to the instruments.

Another part of the experimental system for student use, the statistical column, was designed and built in-house. This column can measure a broad variety of two-phase flow parameters (including flow-pattern related phenomena) as a random process that uses capacitive, resistive, and optical measurement systems in order to monitor flow patterns and in-situ concentration. It consists of both hydraulic and electronic systems (including ELVIS) as shown in Fig. 2. The hydraulic system consists of a vertical test tube, three measurement systems (capacitive, resistive, and optical), air pressure and flow meters, and an air compressor. The electronic system consists of a computer-aided data acquisition system (CADAS) and a prototyping board with electronic circuitry (built by students according to written instructions and using simple electronic elements) that are then interfaced to NI ELVIS. After the measurement system was built, calibrated, and interfaced successfully to ELVIS, the student groups performed the experiment by following the second part of the written instructions. There were many different experiments that allowed the students to learn various aspects of instrumentation and measurements. These experiments were also well-suited to prepare the students gradually to apply their knowledge to the development of the OEPs and to conduct the most complex class experiment (as shown in Fig. 3). In the most complex class experiment, the student, following the written instructions, built three measurement systems (capacitive, resistive, and optical), connected three sensors to the vertical test tube, and interfaced this to ELVIS (as shown in Figs. 1 and 3). After the measurement systems were built, calibrated, and interfaced successfully to ELVIS, the student group performed the experiment by following the second part of the written instructions. This part of the experiment involved gathering data for voltage signals vs. times from the three sensors for different flow patterns. The results of this are shown in Fig. 6, which shows an optical system that is controlled by air pressure and its flow rate. Using MatLab, LabVIEW, and spreadsheet software, the students calibrated the primary dynamic signals by receiving signals for concentration or film thickness vs. time and then transferring those signals into amplitude and frequency domains (Figs. 6 and 7). This was done in order to evaluate the concomitancy of the measurement systems and to answer questions about the impact of the controlled independent parameters (flowrates, pressures, etc.) on the dependent parameters (concentration, film thickness, etc.).

The decision to use capacitive, resistive, and optical sensors for the experiment was based on how frequently those three sensors are used in mechanical engineering applications for the measuring of stress, displacement, motion, pressure, temperature, concentration, film, level, surface properties, lubrication quality, cavitation, and velocity. Likewise, because this particular approach involved experiential learning and building everything from scratch, it exposed teachers and students to the key issues of instrumentation and measurements, including sensor and transducer design and application, signal conditioning, troubleshooting, calibration, computer-aided data acquisition with data analysis and validation, the design of experiments, signal analysis for deterministic and random processes, error and uncertainty analysis, and communication issues such as the analysis of electronic databases, report writing, and oral presentations.

For this new hardware and software, new teaching experiments and experimental setups needed to be developed for both classes. The first four structured experiments for the first class were designed so the students would gain hands-on experience with electrical measurements and basic electronic systems such as multimiters, signal generators, analog oscilloscopes, capacitors and resistors, Wheatstone bridges, and the computer-aided NI ELVIS system (which was used extensively in both classes). This allowed the students to understand how to use these instruments as well as how to write lab reports and proposals.

In the fifth experiment (included in Appendix), students become familiar with using the computer-aided NI ELVIS system as a tool for obtaining and analyzing a dynamic signal measured from the statistical column. This experiment consisted of two parts. The purpose of the first part was to measure the resistance of an opto-resistor by using a board-built Wheatstone bridge. The purpose of the second part was to obtain a dynamic signal as a gas-liquid mixture was flowing through the statistical column. The signal was obtained by measuring the voltage across a Wheatstone bridge, which included an opto-resistor that was mounted perpendicular to the flow. A flashlight provided light to the opto-resistor from the opposite side of the statistical column. The voltage signal was viewed using a computer-aided digital oscilloscope, and it was recorded for low, medium, and high pressure inputs.

In the sixth experiment, students familiarized themselves with static calibration techniques and dynamic signal measurement methods. In part one, the objective was to measure the resistance of a linear potentiometer and find calibration characteristics as the displacement varied. The error was then calculated by comparing the measured resistances with the best fit line. After building a Wheatstone bridge with a thermistor, the calibration was conducted by using values that had been calculated from the manufacturer's formula and then placing the thermistor in water with known temperatures (hot, room temperature, and cold). The voltage signal across the Wheatstone bridge that the thermistor was attached to, was then analyzed with NI-ELVIS's digital oscilloscope. In the third part of the experiment, the thermistor was transferred from the hot water to the water at room temperature and then to the cold water. The registered transient signals were recorded and analyzed in order to find a time response to the thermistor.

In the seventh experiment, the student became familiar with measuring RPMs in a mechanical system (another typical mechanical parameter) by using a stroboscope. This experiment was also designed to allow students to use their intuition and creativity to develop an alternative measurement approach that was concomitant with the first method. The differences between the two methods was then compared and analyzed in order to validate the experimental results of the DC motor's RPMs vs. voltage supply. Many different systems, including those based on opto-resistors or switch type sensors, were proposed and investigated. The students then conducted measurements in order to establish the compressor characteristic of flowrate vs. power supply.

The eighth structured experiment in this class was designed to familiarize students with Op-Amp circuits as well as the NI ELVIS system and its applications. This experiment was also designed to provide the knowledge that would be needed in the next semester for performing measurements of mechanical parameters as a part of a low-pass filter. Three basic operational amplifier circuits were investigated: a voltage follower, a non-inverting amplifier, and an inverting amplifier. Each circuit was tested with DC input and AC input voltages. The output voltage levels were measured and the amplitude and phase relationships between inputs and outputs were documented.

The structured experiments in the second semester class started with applying a pressure sensor application to a dynamic pressure signal from a membrane compressor using the NI ELVIS system and prototype boards. This activity refreshed the students' knowledge from the previous semester and allowed them to further hone their skills of dynamic signal gathering and analysis in the measurement of mechanical parameters. The students measured output voltage levels and generated calibration curves between supplied compressor voltages and pressures.

The goal of the second experiment was to prepare the students to build and use an AC bridge in the future. This required the use of a low-pass filter for interfacing into the NI ELVIS system. Students were required to build and utilize a low-pass filter for further applications including the NI ELVIS oscilloscope and prototype boards in order to measure dynamic voltage signals.

In the third experiment, students experimented with the properties and applications of low-pass filter circuits based on op-amp using NI ELVIS fixtures like oscilloscopes and prototype boards for the measurement of dynamic random signals. Students also learned how to identify the quality of gathered signals as well as how to analyze them.

In the fourth laboratory experiment, the students built an optical system on a statistical column that was interfaced to the computer, and then ran experiments of dynamic signals controlled by flow conditions in the statistical column. By building the Wheatstone bridge, the students learned how to achieve the correct sensitivity of the bridge by using a potentiometer and a photocell in order to find the correct resistance value of a Wheatstone bridge. A variety of flow patterns, including dispersed bubble flow, bubbly flow, and churn flow, were observed and analyzed. Results of this lab demonstrated how to control, observe, and analyze randomly varying voltage signals that had been impacted by the flow patterns.

The fifth laboratory experiment involved using the AC Bridge and the capacitive sensor installed in a statistical column (and interfaced via the AC Bridge to the NI ELVIS system) for the dynamic measurement of random mechanical processes. Before the main part of the experiment, students had to build and troubleshoot an AC Bridge with a low-pass filter and then use this system for the gathering of data. The first part of the lab used capacitive sensors with an AC bridge but without a low pass filter. The second part of the lab used capacitive sensors with an AC bridge with a low pass filter. A variety of flow patterns, including dispersed bubble flow, bubbly flow, and churn flow, were observed and analyzed. Data for primary signal voltage vs. time were transferred during the calibration process to the in-situ concentration vs. time. The students also analyzed the data in time, amplitude, and frequency domains, and compared the signals with and without the filtering process.

The sixth experiment applied dynamic measurements of random mechanical process using the Wheatstone bridge and the resistive sensor (installed in a statistical column and interfaced via the Bridge to the NI ELVIS system) to gather data of in-situ concentration vs. time, which are concomitant to the data from a capacitive sensor. The concomitancy was then used to validate the measurements. The collected data was compared to the results from concomitant measurement systems as a part of the data validation process. Before the main part of the experiment, students had to build and troubleshoot a Wheatstone bridge on a prototyping board and then apply this system to the gathering of data. A variety of flow patterns, including dispersed bubble flow, bubbly flow, and churn flow, were observed and analyzed for the same flow conditions used in the fifth experiment. Data for primary signal voltage vs. time were transferred during the calibration process to in-situ concentration vs. time. The students also analyzed the data in time, amplitude, and frequency domains and compared the data to the data collected from the capacitive system.

In the laboratory sessions involving controlled and instructed experiments, students are primarily involved with the "Active Experimentation" stage of Kolb's cycle. The importance in this process is placed on doing the experiment and taking data in accordance with supplied instructions.[2] Kolb's model distinguishes *apprehension* and *comprehension* as two independent modes of grasping knowledge, and *intention* and *extension* as independent modes of transforming experience.[2, 3] According to the Kolb's model, in order to learn something from the experiment (which is distinguished as the transformation phase for constructing new knowledge through the experimentation), *requires that the information first be grasped or depicted.*[2] In their work, Abdulwahed and Nagy[2] prove that if an insufficient amount of attention is paid to pre-lab student activities during instructed and close-ended laboratory sessions, then the students primarily grasp information about the experimental procedures. However, they only partially grasp the theory that underlies the laboratory procedure. During his specific teaching experience, the author observed very similar effects, which resulted in poor learning outcomes for the laboratory session. This was related to poorly developed student activities before they came to the lab. As a result, the lab experiment turned into a mechanical exercise of following the lab manual instead of an exercise where the students actively built meaningful knowledge during the process. Over the next semester, structural changes are planned which will intensify the pre-lab activities, and which will require the students to be much more prepared before coming to a laboratory session. This should ultimately make the students' learning process more successful and efficient.

The Final Project

After the students developed their basic understanding of and hands-on experience with basic measurement procedures and tools[8,9], computer-aided data acquisition, signal processing, uncertainty and error analysis, and communication procedures, they then begin to implement these skills into an open-ended project (OEP). This is a single, final, two-semester long project which varies partially from year to year. The goal of the OEP is to give the students some opportunities to gain experience in research, in the design of a completed system, and in the conducting of a feasibility study that includes a final report and presentation. Although these reports are not of the quality of professional scholarship, these reports, along with the presentations and the developed hardware, clearly demonstrate what the students have learned. Many of these reports present repeatable, accurate results, and some of them include an in-depth analysis of the computer-aided measurement system development (see Fig. 2), calibration, uncertainty, and error-analysis of the measurements. All of the OEP groups built self-contained working prototypes, which included concomitant sensors, transducers built on prototyping boards and scaled down from a vertical column. They also conducted experiments as a part of a feasibility study and validated their measured results using concomitant measurement systems. It was evident that the students cherished the opportunity to transfer their design ideas into the form of a working prototype. Some groups enjoyed the freedom of conducting research on their own completed system and even spent extra time in the lab trying to work out an additional idea. However, because this was the students' first serious exposure to hands on experimentation and the need to apply interdisciplinary knowledge and to check it, many of the students had to spend additional time learning how to successfully troubleshoot their systems.

As part of the teaching tool in these classes, an open-ended project is used in which the issues that need to be solved are designed to be realistic, complex, state-of-the-art, and challenging. The objective is to generate and intensify enthusiasm among the students and to prepare them more substantially for the "outside" world using a discovery approach. It is crucial for the students to understand that the discovery process is one in which they are active participants, not passive observers. In processes like this, faculty members and students become learners and investigators simultaneously. Their active participation makes for a more effective learning process beneficial to both parties. At the beginning of the first semester, a full-cycle learning experience in OEPs begins with the development of an initial unique idea. It then continues on to the design and construction of a working prototype including CADAS, and concludes by conducting a feasibility study involving the design of experiments, start-up procedures, data gathering and analysis, report writing, and a presentation. This means that the OEP contains a full-cycle experiment from inception to implementation.

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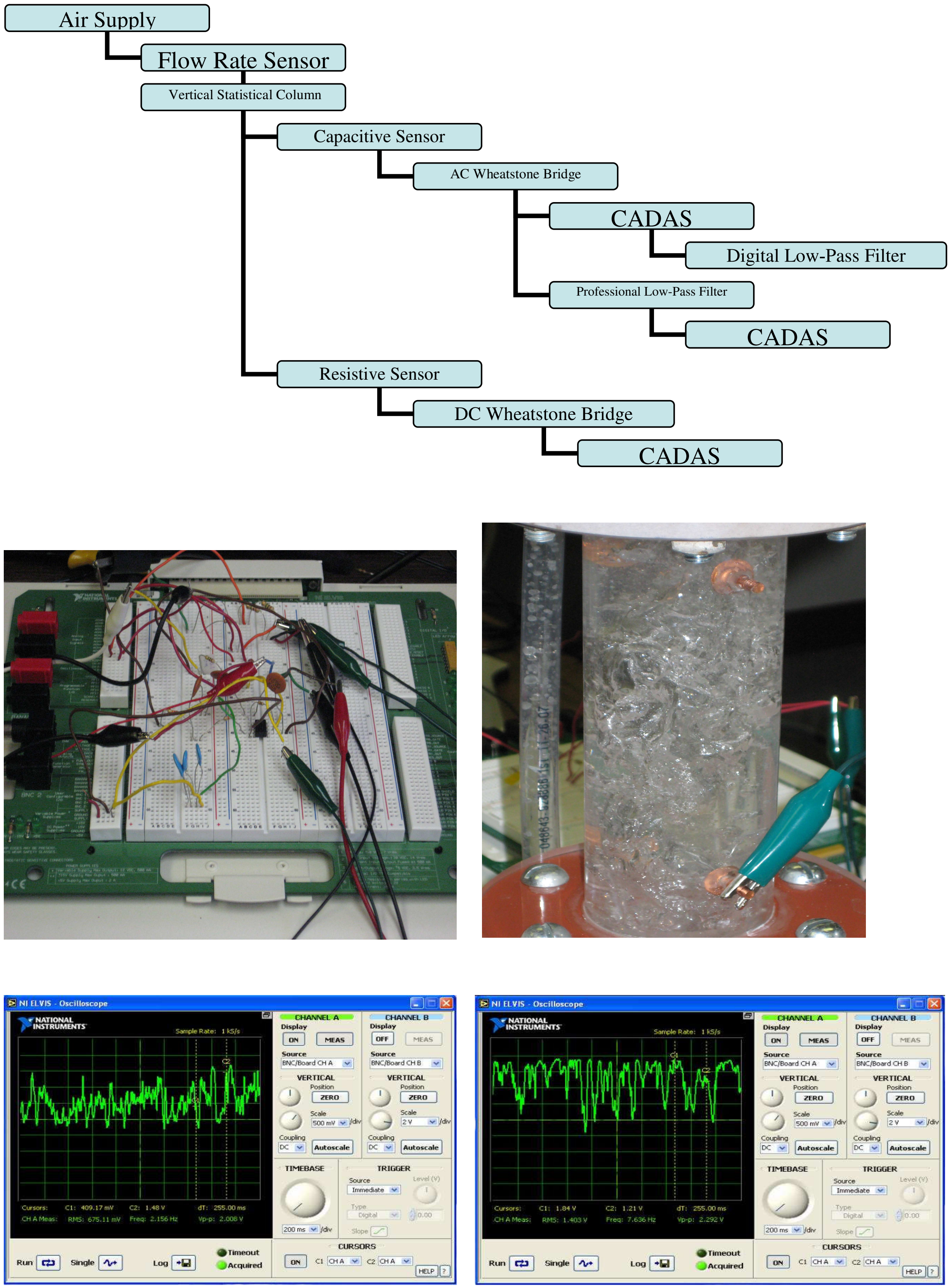

Figure 5: Structured Experiment with Data Validations. Block Diagram of the Circuitry (top), and the Bench-Top Workstation with Circuitry on the Prototyping Board (center left), and Column Experiment Set-Up (center right). Digital Oscilloscope View of the Signals from the Column (bottom).

An effective way to begin the OEP is by selecting quality references that are feasible in a "learn approach" with limited library resources and whose full-text versions can be found on the Internet. In selecting sources, two key issues are important: (1) that the student uses objective and high quality references, and (2) that the source contains state-of-the-art information. In this case, the most important sources of information are refereed journal papers and patents. The student's limited subject knowledge, coupled with a plethora of relatively easy accessible scientific (and mostly pseudoscientific) information on the Internet, creates a situation that requires a knowledgeable faculty member to be intensively involved during the teaching process. This includes defining the criteria for evaluating quality sources before they can be used in the learning and application processes.

Due to the broad spectrum and ready accessibility of materials on the Internet, there is also the ever-present danger of plagiarism. Consequently, the instructor should clearly explain the ethical and judicial repercussions of plagiarism. This will hopefully guide the students to police their own practices.[10] Because OEPs require the students to do independent study on the subject and to define a unique idea using limited knowledge, another good resource is the US patent database. Because each patent must have at least one cookbook-type recipe concerning how to implement the idea, this makes patents a valuable source for students working on OEPs. However, in the case of patents the instructor needs to very carefully guide the students in their selection of good quality patents. Even though most high quality sources of information are refereed papers and technical reports, finding and evaluating these sources can often be confusing for students. After using the Compendex index, however, the potential confusion over what is and what is not a refereed paper can usually be avoided.

At the beginning of the first semester, the professor issues requests for proposals and then collects them from the students. After a few attempts and changes, teams and proposals are usually accepted (teams consist of one to three students). Each team then begins to work on the OEP by performing a background literature search and analysis. Based on the search and analysis, teams design their first prototype as well as the experiments that will be used in their study program. They also define the deliverables and the success criteria for their OEP final product. During the process, there are many check points and

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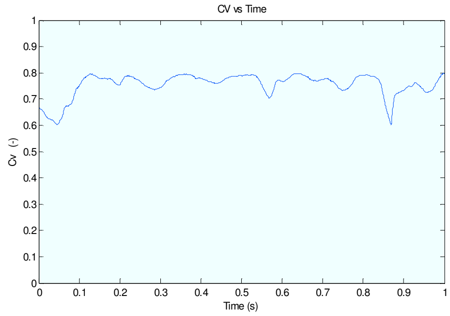
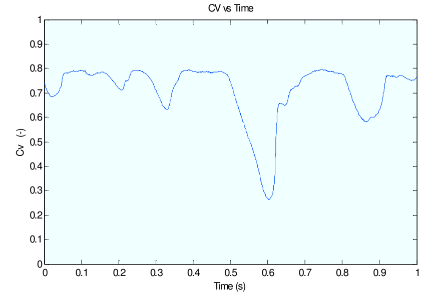
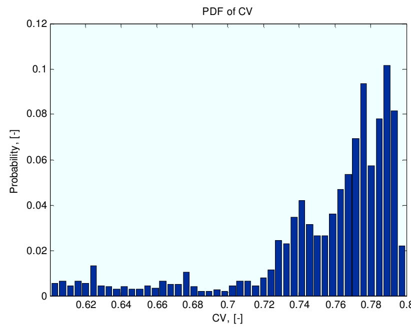
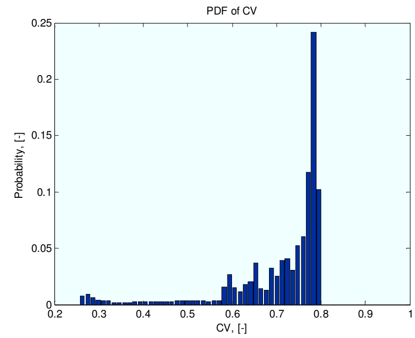
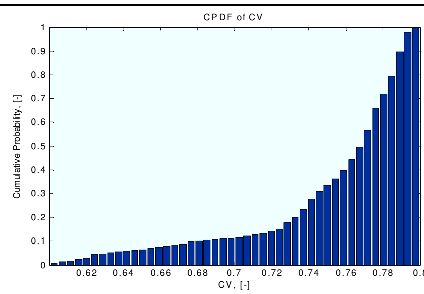
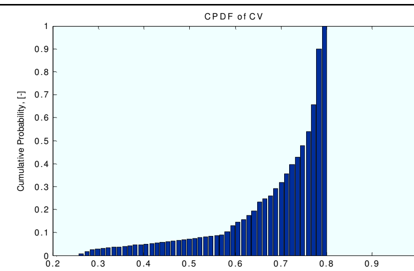
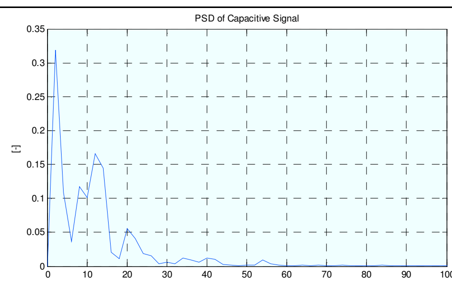
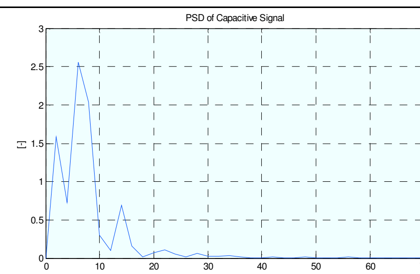
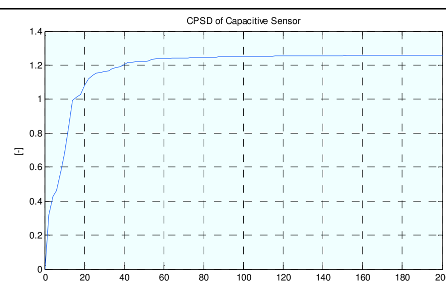
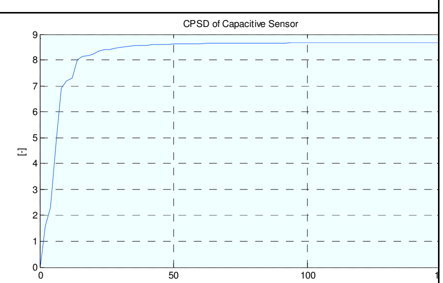
Concentration		
PDF		
CPDF		
PSD		
CPSD		

Figure 6: Comparison of Two Signals in Time, Amplitude and Frequency Domains

open labs where the student teams work on their prototypes and interact with instructors. The first significant graded checkpoint comes at the end of the MCHE 357 class (first semester). This is when each team submits their first report based on the preliminary feasibility study results and the instructor's recommendations for changes. If the report is accepted, it is graded and returned to the students with feedback. If a report is not accepted, it is returned to the students with a list of deficiencies allowing the students to rework and resubmit the report. In the second class, the process continues. Students rebuild a preliminary prototype, conduct a feasibility study, analyze data, write a final report, and make a final presentation at the end of second semester. Figures 5 through 8 demonstrate examples of the hardware and results of analysis used in the OEPs. Very limited examples of data analysis conducted in the OEP are shown in Figures 6 and 7. Figure 8, shows the completed OEPs with final prototypes after the second semester (MCHE 358 in fall 2008). All of these prototypes were completed in the fall semester of 2008.

Fig. 7 View of an Electronic Circuitry of DC and AC Bridges with a Low-Pass Filter on Prototyping Boards Built by Students for an OEP.

Figure 8: Completed OEP Systems in the Fall semester of 2009.

Summary and Conclusions

This paper has reported the results and experiences of the development and implementation of hands-on laboratory experiments in a newly-developed laboratory for Instrumentation and Measurements. The course Instrumentation and Measurements, conducted at the undergraduate junior level in the Mechanical Engineering Program, was a two-semester course for a total of four credits and took place in conjunction with a one-hour classroom lecture and a three-hour laboratory. The development process of this laboratory began with the writing of a successful proposal for outside funding for a hands-on teaching laboratory. After developing the lab's concept, the next step involved finding the right approach and acquiring the tools that were reasonable in terms of price, size, complexity (computer-aided system), and minimal maintenance requirements. The choice was the NI ELVIS system, which is used extensively in many instructional electrical and electronics engineering laboratories. Its application within mechanical engineering programs has required the development of completely new experiments that involved newly-designed hardware, which, in this case, was developed and built in-house. The process of developing a hands-on laboratory presented difficulties in the beginning. The students were required to progress significantly in relation to their previous laboratory approaches, and all new developments had to be implemented immediately into the teaching process. Despite all of these obstacles, however, students slowly came to understand and appreciate the new learning opportunities developed in this approach.

In order to expand the students' exposure to the practical application of knowledge and to encourage their creativity, a two-semester long, open-ended project required the students to find a problem's solution using creative approaches. Consequently, a full-cycle learning experience took place that involved solving real, technical, state-of-the-art problems. This began with the development of an initial idea, continued through the design and construction of a working prototype (including both the system and the measurement sensors on prototyping boards in ELVIS), and concluded by conducting a feasibility study finalized by the writing of a report and an oral presentation

If there is not enough attention paid to the students' pre-lab activities, the students primarily grasp the experimental procedures and only a very limited amount of the theory underlying the laboratory procedures. Consequently, the students are not prepared when they come to the lab and the lab session turns into a automatic following of the lab manual instead of a session involving the active building of meaningful knowledge. In order to improve on this, some structural changes will be implemented next semester that focus more intensively on student preparation before coming to a laboratory session. This will make the students' learning process more successful and efficient.

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Dr. Keska is an Associate Professor and a member of the Graduate Faculty in the Department of Mechanical Engineering at The University of Louisiana-Lafayette. Although most of his experience is in higher education in the United States and Europe, he has been employed in the private sector (Copeland Corporation, Technicon Instruments Corporation) as well as in government laboratories (Pacific Northwest Laboratory, Argonne National Laboratory). He has also served as an industry consultant. His expertise is in the areas of Micro-Electro-Mechanical Systems (MEMS), fluid dynamics of complex heterogeneous mixtures (multiphase, slurries, etc.), tribology, micro heat exchangers with phase transition, computer-aided measurement systems and instrumentation, electromagnetic sensors, turbulence and flow pattern phenomena in mixtures, deterministic and random signal analysis, and data processing and validation. His work has been published internationally in more than one hundred refereed journals, conference proceedings, books, and monographs, and he has been granted more than twenty patents worldwide.

Appendix B

Lab instruction for application of optical sensor in a vertical column

MCHE 357 - MEASUREMENTS - LABS

LAB 5: DYNAMIC SIGNALS. COMPUTER-AIDED EXPERIMENTATION (NI ELVIS) AND STATISTICAL COLUMN

Objectives:

1) To introduce and familiarize the student with a Computer-Aided Experimentation tool (NI ELVIS) and the basic electronic measuring equipment that is used in conjunction with mechanical measurements.
2) To build, apply, and master a Wheatstone bridge application for computer interfacing of signals from a statistical column [3, 5].
3) To apply and master error analysis procedures.
4) To improve the student's communication skills through the generation of a lab report for this experiment.

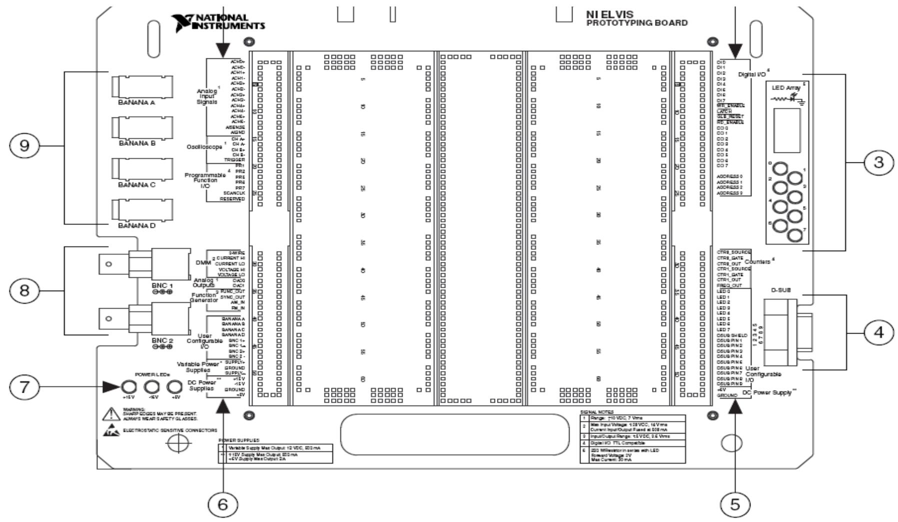
Prelab Activities:

Prior to the lab class, you should study the laboratory instruction and manual for the NI ELVIS (H-drive) [5]. The NI ELVIS is a Computer-Aided Experimentation tool that you will be using extensively in both classes. Mastering this tool is crucial for successful participation in this class. You need to understand the uses and function of the major controls and tools available in ELVIS, especially how to interface a dynamic voltage signal from a Wheatstone bridge built on the prototyping board to the computer and how to visually observe the signal on a Digital Oscilloscope (DO). It is also crucial that you understand how to take measurements and keep records of the output signals [3]. You should review your experiments (Wheatstone bridge components, opto-resistor as a part of your transducer) from previous week experiments. You should also be familiar with the following parameters of periodic waveforms—AC, DC, Vpp, Vp, Vrms and Vavg—and how to measure and calculate them, including precision error calculation and checking and eliminating outliers from your recorded data [1, 2, 4]. To be ready for this experiment, you will need to effectively complete your prelab activities. This will allow you to concentrate on the experiment and process itself rather than just passively following the lab instructions. Before the lab test starts, be prepared to complete a test assessing the level of your preparation for this experiment, The test will be worth 20% of your lab grade.

NOTE: Always check the manufacturer's specifications and instructions for equipment you plan to use. Connect your electronic devices before turning the power on. Turn down all power sources to the minimum output. Check circuits carefully. Before you start your experiment, be sure that you have a full grasp of your experiment and that you have a form ready to record your primary experimental data. Then, turn on the power. During the entire experiment, monitor the current and temperature of the electronic elements you are using. Always ask questions of the lab instructor. After you finish the experiment, inform and discuss issues related to the experiment with your lab instructor, and obtain the lab instructor's signature. After that, remember to disconnect all wires and turn off all equipment (except computers and ELVIS systems) and return them to their primary location, including toolboxes. Cleaning procedures are also part of your experimental procedure.

Equipment:

Multimeter: Fluke 8062A
Function generators: BK PRECISION 3010
NI ELVIS
Photo-resistor
Resistors and potentiometers
Protoboard
Batteries
Statistical column



1 AI, Oscilloscope, and Programmable Function I/O Signal Rows
2 DIO Signal Rows
3 LED Array
6 DMM, AO, Function Generator, User-Configurable I/O, Variable Power Supplies, and DC Power Supplies Signal Rows
7 Power LEDs

Fig.1. NI ELVIS Protoboard

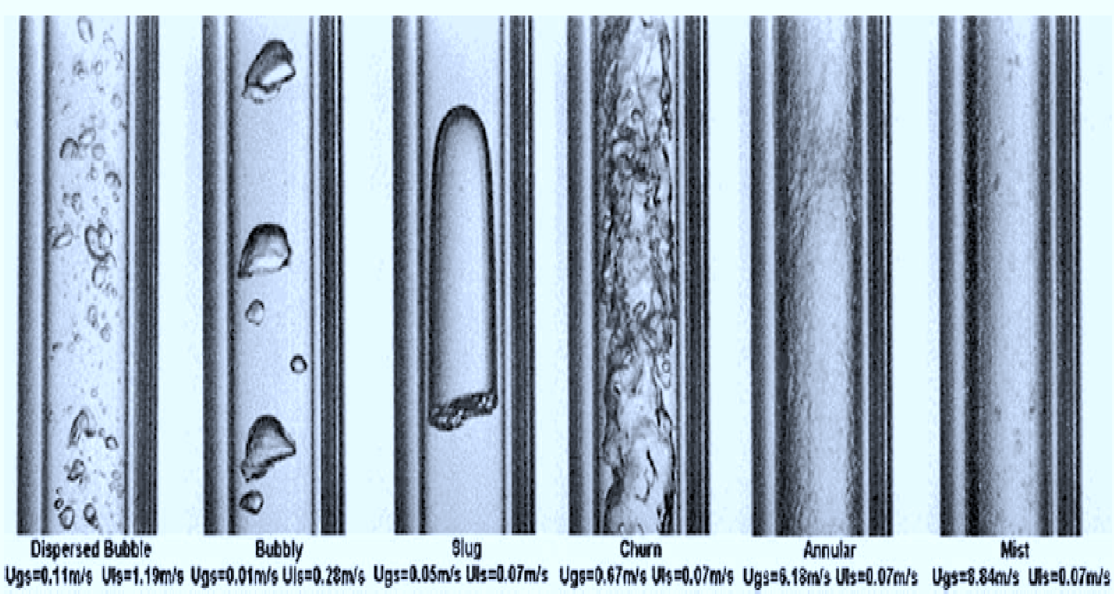


Fig. 2. Flow patterns observed in the present experiment (4.26 mm internal diameter tube at 10 bar).

Fig.3 A. Statistical column with NI ELVIS System

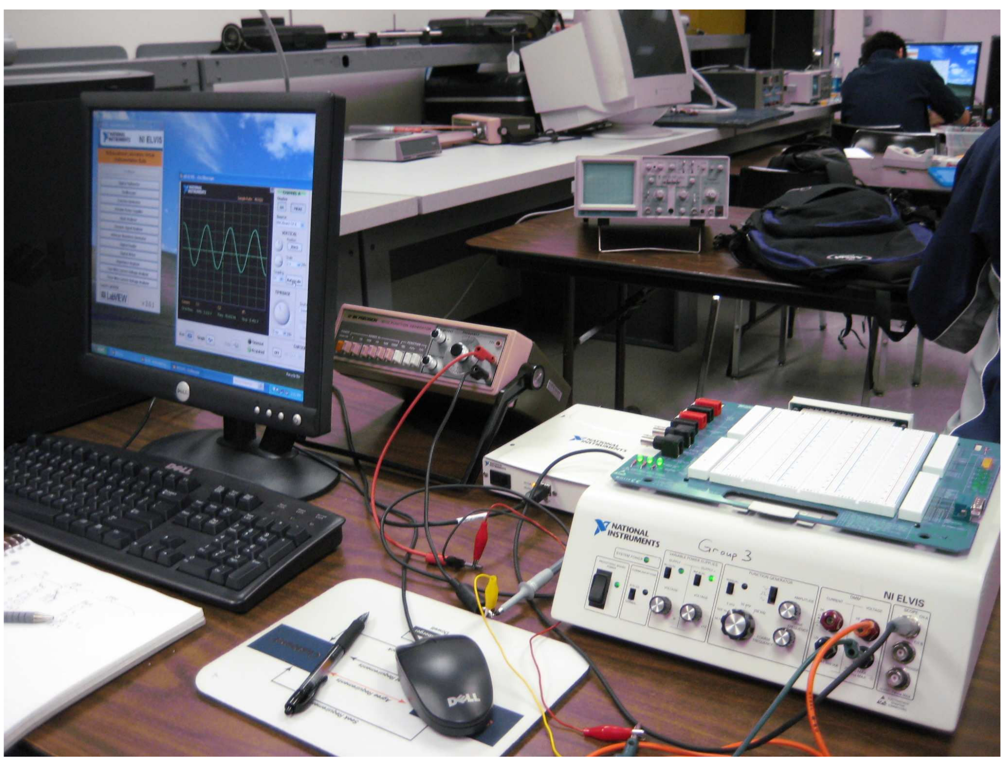


Fig.3 B. NI ELVIS System Ready for Experiments.

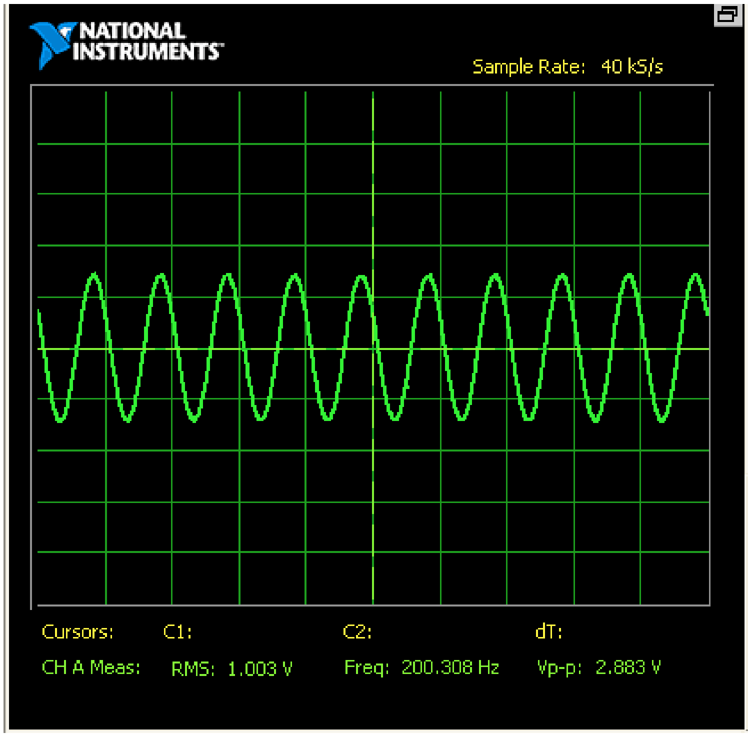


Fig.4. Sinwave Signal on DO in NI ELVIS.

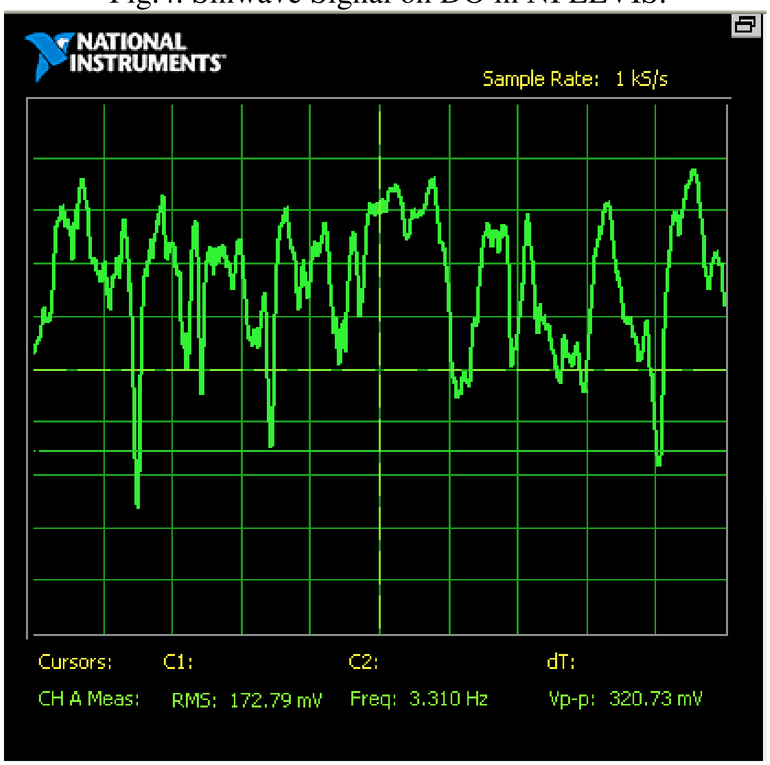


Fig.5. Signal Voltage vs. Time on Channel A on DO from an Optical Sensor.

Lab Tasks:

Before you begin your experiment, please prepare your laboratory record sheet, including the tables for the recording of your primary data. Once you have finished this, complete the following tasks:

1. Take the hydraulic column to your bench. Using a vernier and a ruler, take all the characteristic measurements that are needed for your ACAD sketch in your lab report. You should also use the camera to take pictures to include in your lab report. Fill the column with water and connect it to the pressurized air.

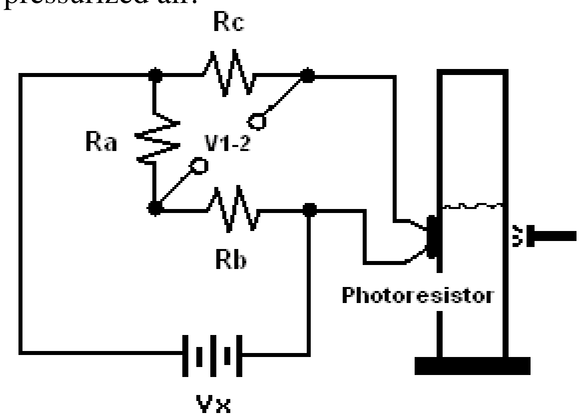


Figure 6: Wheatstone Bridge Configuration for Optical Sensor

Familiarize yourself with the operation of the statistical column (SC), including how to control and observe flow pattern (see Fig.2) change by controlling the input pressure and initial water level in the column [5]. Get familiar with operation of the column, controlling and observing flow pattern change by controlling the input pressure starting from minimal pressure and observing initial and maximal water levels in the column. You can enhance your ability to observe flow patterns by using the stroboscope light (freeze motion).

(2) Using the resistors, build a battery powered Wheatstone bridge on an ELVIS prototyping board using a potentiometer and optoresistor. Using this potentiometer find the right value of resistance and replace it with a fixed resistor, then use the bridge to measure the resistance of your opto-resistor for ambient and enlightened conditions. Be sure that each of the WB's resistor is larger than 1 kOhm and that the WB produces an output voltage difference of at least 0.5 V for the battery, and 1.3 V for ambient and enlightened conditions.

(3) You previously-built a battery-powered Wheatstone bridge on the prototyping board. It can operate in "near-null" balance conditions for an optoresistor. It should be connected to the optoresistor, attached to the column between two plates (either in a reflective or a translucent mode). Interface the WB with the NI ELVIS. With the column running, record the signal using an NI ELVIS Digital Oscilloscope (DO). During this process, be aware of a "parasite" frequency near 60 Hz, coming from ambient light. For each run, be sure to make notes about input pressure, water static and maximal levels, and other aspects so that you will be able to repeat the same conditions in your next experiment. After this, introduce compressed air into the SC at the minimum level (very low air flow – single bubbles). Then, make an electronic record in AC mode using time intervals (sampling frequency 1 kHz), allowing for 8 to 10 full cycles of the signal. Record your observations (pressure, water levels, photo, etc.) and take traces of your signals vs. time. Reduce the air input to zero and check if the signal on your DO is constant. In the next step, increase the flow intensity somewhere between your minimum and maximum flow. Record your signals, repeating the procedure as before.

After this, increase your airflow to the maximum value and record your data. Take at least two signals for each condition. Eventually you will have the option to disregard one signal and use another. Calculate average value and standard deviation for each signal and check for outliers and disregard them if there are any. After that, calculate average value , standard deviation and precision error for each signal again. From your ratio of static and maximum water heights, calculate an average concentration for each condition and generate a chart of error vs. concentration.

Check the signal character with your lab instructor and obtain his written approval on your lab sheet. The signals should be in a format that can later be imported to a spreadsheet with two columns: time and voltage. Transfer it into a spreadsheet or into MatLab and draft a chart showing voltage v. time.
Repeat the last part of step 3 for two other pressure levels. In total, you should collect at least three signals for different flow patterns. For each flow pattern, record the input pressure, the water levels, the sensor location, the sampling frequency, and the RMS value of the voltage (to compare later to your RMS value from DO and calculate from your spreadsheet data).

For each of the measured signals, generate a sine-wave signal with a frequency and amplitude that best fit into the signal from the column. Then use these signals as a reference in your data analysis.

To prevent surprises, always check your findings and the signals with the lab instructor and obtain his written approval on your lab sheet.

THIS ENDS TODAY'S LABORATORY. REMEMBER TO DISCONNECT ALL OF YOUR WIRES AND TURN OFF ALL YOUR EQUIPMENT EXCEPT FOR THE COMPUTER. CLEAN YOUR STATION UNTIL IT LOOKS LIKE IT DID AT THE START OF THE LAB!