The Application of a Computer-Aided Data Acquisition System (NI ELVIS) during Physical Experimentation in an Undergraduate Mechanical Engineering Program

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Abstract

In order to increase student interest and the student's own creative, hands-on, problem solving skills, a unique and innovative approach has been implemented that creates an opportunity to push students to use their creative limits. Through the instructional use of design, unique experiments, and open-ended projects that formulate and investigate realistic, inventive and complex problems students received more closely aligned classroom topic with industrial standards.

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. Also, a very important part is a two-semester long, open-ended project (OEP) utilized a process which required the students to come up with creative approaches to problem solving. A full-cycle learning experience took place. After acquired necessary minimum knowledge, the students began their OEP with the development of an initial idea, continued on through the design and construction of a working prototype (including both system and measurement sensors on prototyping boards in ELVIS), and concluded by conducting a feasibility study, which involved writing a report, and giving a presentation. Because the ELVIS system is used mostly in many instructional electrical engineering laboratories, an extensive process of adaptation to mechanical engineering needs was implemented and the development of completely new experiments involving newly designed hardware and instructions had been developed and built in-house with student participation.

Introduction

In the undergraduate teaching process, both instructors and students often get bored solving simple textbook problems that have limited connections to the real world and require little, if any, imaginative thinking to solve. To increase student interest as well as the student's own creative, hands-on, problem-solving skills, a unique and innovative approach utilizing open-ended projects has been developed that pushes students to their creative limits. This approach, which formulates and investigates realistic, inventive, and complex problems, not only helps increase student enthusiasm, but it also more closely aligns classroom topics with contemporary standard industrial environments.

Although it can be useful to use theoretical and computational tools (including virtual tools) in the classroom to teach engineering processes, the superiority of using experimental approaches is quite obvious. Because these processes use experiments, it is possible to prove a hypothesis and make it a theory. Likewise, a new, successful industrial product development process requires the use of an experimental approach (at least the proof-of-the-concept portion). Consequently, mechanical engineering students need to be equipped with hands-on experience in instrumentation and measurements. This involves conducting physical experiments concerning 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, and how to disseminate results. There are, however, many obstacles that must be overcome in order for this type of process to be successful. The most common obstacle is that the laboratory and shop base that are required for the constant troubleshooting process can cause both a financial burden and a tremendous increase to the instructor's teaching load. These obstacles often force engineering educators to make necessary compromises which oftentimes replace laboratory experiments with virtual experiments and "black board" exercises.

One way to reduce some of this burden is through the implementation of miniature mechanical tools with prototyping sensors and measurement systems as a part of the laboratory class. The students can also use a prototyping board to construct sensors and electronic transducers, which allows the class to get a better understanding of measurement systems. In order to do this, however, the students need additional interdisciplinary knowledge (that they can only get through lecture and by conducting a series of designed experiments) that can then be implemented during the OEPs. Thus, the first part of the class should address the development of sensors and measurement systems and experimentation and data analysis. Using an inexpensive, computer-aided experimentation system like NI ELVIS makes this process even more appealing in today's "lean" approach to engineering education. The second part of the class should utilize statistical analysis, the validation of data using concomitant systems, the design of experiments, scaling-up modeling, and the use of electronic databases on the Internet.

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, is a two-semester course for a total of four credit hours. It involves a two-hour laboratory in conjunction with a weekly, one-hour classroom lecture in mechanical engineering. A modified version of this approach, however, can easily be implemented at all levels of the mechanical engineering curriculum. The development process for this laboratory began by writing a successful proposal for outside funding that was used to develop a hands-on teaching laboratory. Another important component of this process was the use of a two-semester long, open-ended project (OEP), where the students were required to come up with a creative approach to a problem and then design and construct a working prototype and a feasibility study. Consequently, this laboratory was part of a full-cycle learning experience that began with the inception of an idea and concluded with a feasibility study of the working prototype. After the students had acquired the necessary minimum knowledge in the first semester, they began their OEP by developing an initial idea. They then continued on through the design and construction of a working prototype (including both system and measurement sensors on prototyping boards in NI ELVIS), and concluded by conducting a feasibility study, which involved the design of the experiment, the collection and analysis of data, writing a report, and giving a presentation. The computer-aided NI ELVIS system is used primarily in instructional electronic and electrical engineering laboratories. Because of this, an extensive process was implemented in order to adapt it to a mechanical engineering lab and satisfy the needs of a mechanical engineering program. This was accomplished by developing new experiments suited for a mechanical engineering program, newly designed and built hardware, and instructions that had been developed and built in-house using active student participation.

Structured Laboratory Experiments

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. Before the implementation of this newly-designed course, the students had taken a two-semester course for four credits which included a one-hour classroom lecture and three hours of laboratory activities. The laboratory activities in this course, however, were primarily demonstrative, rather than hands-on, and there were very limited applications of computer-aided measurement systems. In association 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 the teaching of these classes.

During the development process, 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 potential as a learning tool for students, we chose to concentrate all the lab activities around the use of an inexpensive, computer-aided experimentation system like NI ELVIS that used prototyping boards, building sensors, and transducers built by students from basic electronic elements and according to a unique design. A statistical column (a key piece of hardware) had been previously designed and it was built in the department’s mechanical shop (see Fig. 1). This piece was a substantial element in the creation of the experimental station (see Fig. 2). For the lab, two major groups of 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 could gain hands-on experience with sensors and measurement systems. They were also designed so the students could learn about data analysis using a computer-aided experimentation system for the application of statistical analysis, data validation using concomitant systems, the design of experiments, the prototyping of systems, scaling-up modeling, and the use of electronic databases from the Internet.

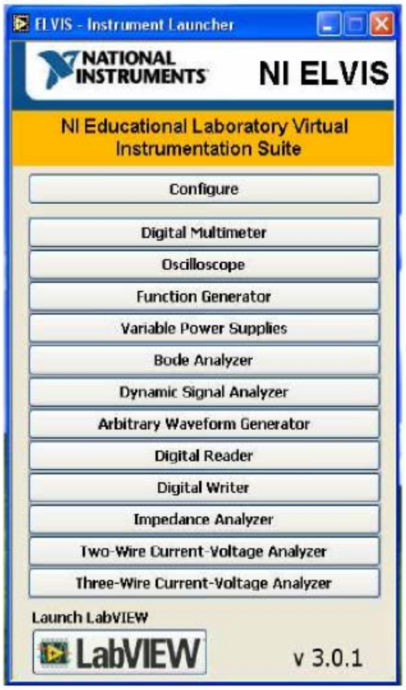
Together, the bench-top workstation and the Computer-Aided Data Acquisition System (CADAS) with the statistical column created a comprehensive and universal laboratory tool that can be used for most structured experiments, including those that involve OEP systems. Via the front control panel, the workstation 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. For example, the function generator’s output can be routed to a specific channel of the DAS device and ultimately acquired on a desired channel in the NI ELVIS. The bench-top workstation also contains a protective board that guards the DAS device from possible damage that may result from laboratory errors.

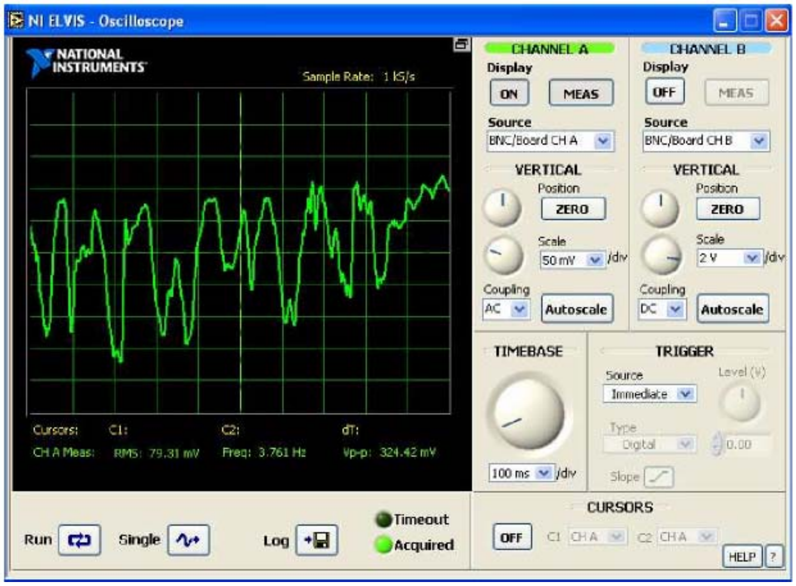
The statistical column, another part of the experimental system for student use, was developed and built in-house. This column can measure a broad variety of two-phase flow parameters (including flow-pattern related phenomena) as a random process that uses capacitive, resistive and optical measurement systems. 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 is built, calibrated, and interfaced successfully to ELVIS, the student groups performed the experiment by following the second part of the written instructions. There are many different experiments that allow students to learn various aspects of instrumentation and measurements. These experiments are also well-suited to prepare the students gradually to make progress in 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 concentration or film thickness signals 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 choice of capacitive, resistive, and optical sensors for use in the experiment was made based on how frequently those three kinds of sensors are used in mechanical engineering applications for measuring stress, displacement, motion, pressure, temperature, concentration, film, level, surface properties, lubrication quality, cavitation, and velocity. Likewise, because this approach involves learning-by-doing and building everything from scratch, it exposes teachers and students to the key issues of instrumentation and measurements: 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.

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 (right), ELVIS Virtual Instrument Suite and the Benchtop Workstation with Prototyping Board (in the middle), and Computer-Aided Data Acquisition System (CADAS) (left).





Sample Rate: 1 kS/s

Cursors: C1: C2: dT:

CH A Meas: RMS: 79.31 mV Freq: 3.761 Hz Vp-p: 324.42 mV

Channel A: Source BNC/Board CH A; Scale 50 mV /div; Coupling AC

Channel B: Source BNC/Board CH B; Scale 2 V /div; Coupling DC

Timebase: 100 ms /div

Trigger: Source Immediate; Level (V) 0.00

Cursors: OFF C1 CH A C2 CH A

Figure 3: ELVIS Virtual Instrument Suite (top left), the Benchtop Workstation with Prototyping Board (top right), and ELVIS Digital Oscilloscope View of a Signal from the Column (bottom).

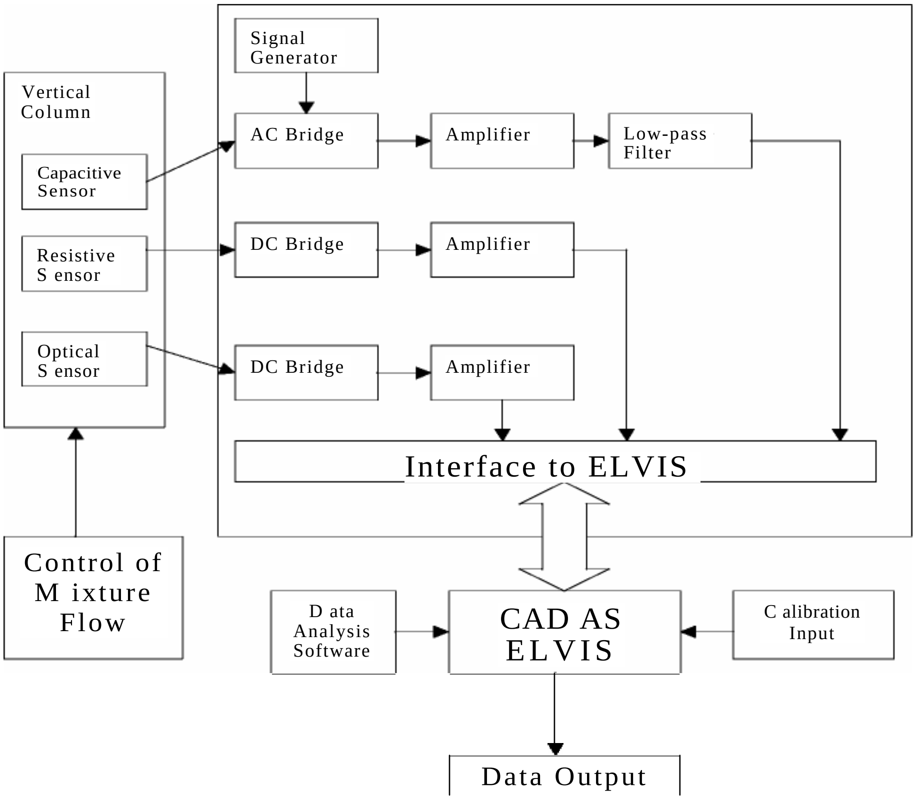


Figure 4: Concomitant Measurement Systems for the Final Structured Experiment with Data Validations.

Figure 5: The Most Complex Class Experiment for Data Validations. Experiment Set-Up (top), and the Bench-Top Workstation with Prototyping Board (bottom).

Open-Ended Project

As part of the teaching process in these classes, an open-ended project is used in which the problems that are presented 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. 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 simultaneously become learners and investigators. Their active participation makes for a more effective learning process that is beneficial for both of them. As it is at the beginning of the semester, applying 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 that includes 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 OEP contains a full cycle experiment from its inception to its implementation in a working a researched prototype.

An effective way to begin the OEP is by selecting quality references that are feasible in a "lean approach" with limited library resources and whose full-text versions can be found on the Internet. In selecting resources, two key issues are important: (1) that the source uses objective and high quality references, and (2) that the source contains state-of-the-art information. In this case, two of the most important sources of information are refereed journal papers and patents. The student's limited subject knowledge, coupled with a plethora of relatively accessible scientific (and 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 rigorous criteria for evaluating quality resources 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. In addition to the fact that the instructor needs to carefully guide the students in their selection of good quality patents, each patent must have at least one, cookbook-type recipe concerning how to implement it in order to be a valuable source for students working on OEPs. In addition to patents, refereed papers and technical reports on the subject are also quality resources. Finding and evaluating these resources, however, can oftentimes 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.

The OEP activities implement the following steps:

1. An introduction to the creative thinking process and its implementation by finding a solution to a challenging problem. This involves a full cycle of activities that includes a study of the resources, brainstorming to create alternative solutions, the design and construction of the first prototype (including a feasibility study with data analysis, prototype evaluation, and redesign), and the generation of an engineering report and final presentation which documents the design, development, testing, and evaluation of the end product[1, 2, 3].

2. The background search and study of closely related solutions to the issue (refereed journal papers, patents, web sources, and e-library materials), which provide comparisons to the approach and its implementation in the OEP process[4, 5, 7, 10].

3. The introduction and application of uncertainty and error analysis, which includes an error reduction process and data validation[6, 8, 9].

4. The development and calibration of needed measurement systems[8, 9].

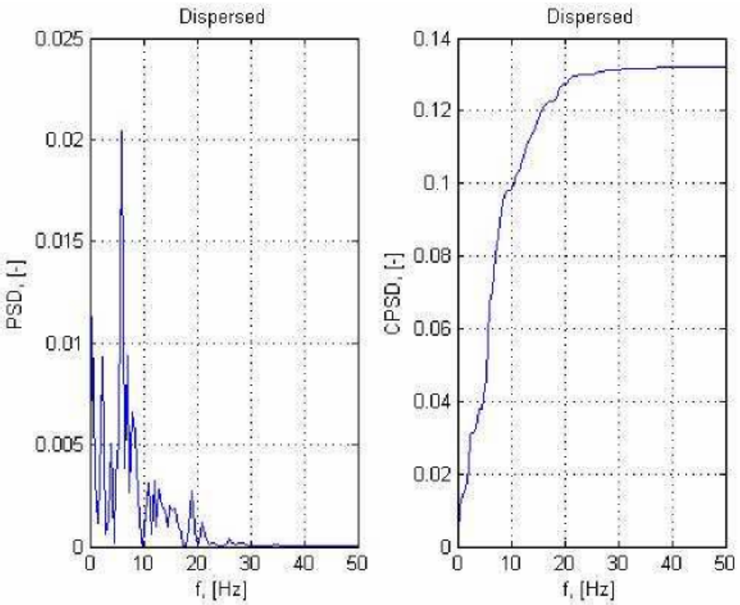
5. The application of computer-aided experimentation and research processes using tools such as Matlab, CADAS, the Internet, Lab VIEW, spreadsheets, graphics software, and other electronic tools.

6. The prediction of the results based on theory and the application of a phenomenological approach coupled with physical experimentation and experiment design in order to verify the theory and the assumptions used.

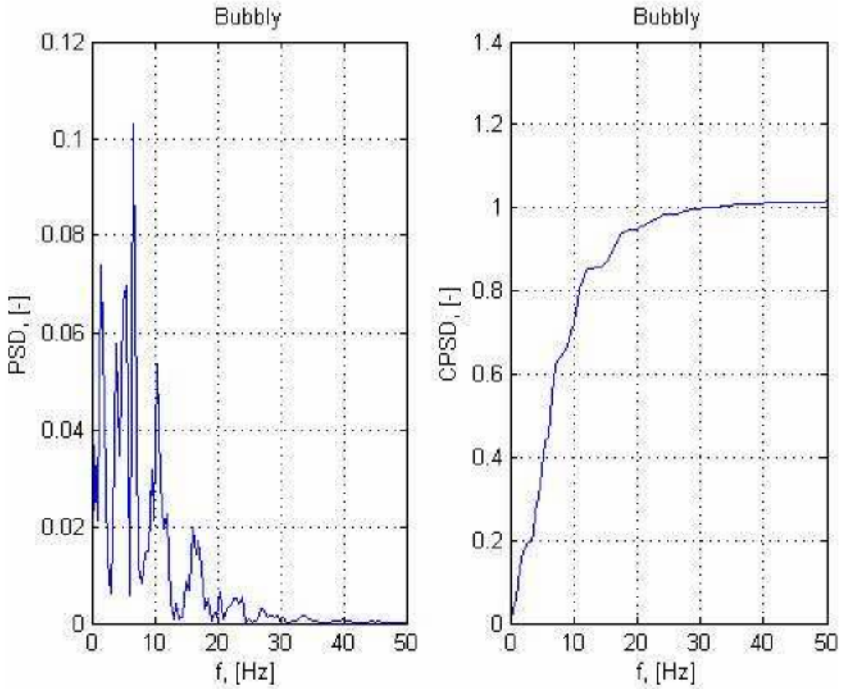
7. The application of data analysis and verification techniques (bias and precision errors, literature comparisons, concomitancy and redundancy).

8. The use of computer-aided communication and the dissemination of results (class and conference presentations, reports, and publications).

At the beginning of the first semester, the professor issues a request for a proposal and then collects them from the students. After a few attempts, teams and proposals are usually accepted (teams consist of one to three students). The teams then begin 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 open labs where the student teams work on their prototypes and interact with instructors. The first 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 listed deficiencies so that the students can address them and resubmit the report. In the second class, the process continues from the first class, and it involves rebuilding a preliminary prototype, conducting a feasibility study, analyzing data, writing a final report, and making a final presentation at the end of second semester. Figures 5 through 8 demonstrate the hardware used in the OEPs. The top row shows the preliminary prototypes after the first semester with limited measurement systems. The bottom row shows the final prototypes after the second semester. All of the presented prototypes were completed in the fall semester of 2008. Examples of data analysis conducted during the OEP are shown in Figure 6.



Capacitive Sensor Dispersed Bubbly



Resistive Sensor Dispersed Bubbly

Fig. 6: Power Spectral Density (PSD) and Cumulative Power Spectral Density (CPSD) of Spatial Concentration Measured by Capacitive Sensor in Dispersed Bubbly Flow

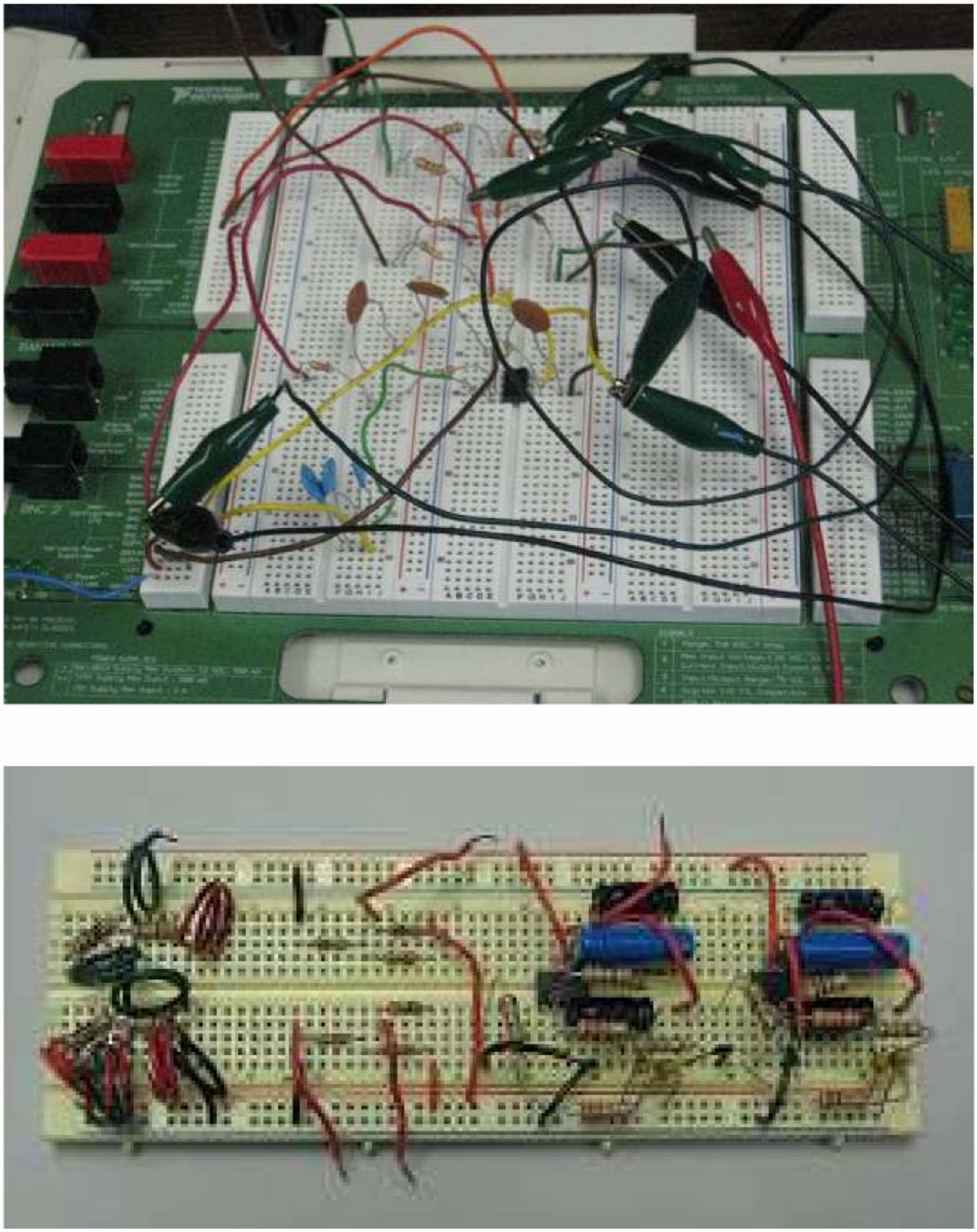


Fig. 7 View of an Electronic Circuitry of an AC Bridge with a Low-Pass Filter on the ELVIS Prototyping Board Build by Students.

Figure 8: OEP Systems Completed in the Fall semester of 2008. The Top Row the Prototypes after First semester. The bottom row shows the final prototypes after the second semester.

Summary and Conclusions

This paper has described 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, aimed at 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. The development process for this laboratory began by writing 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 to use in terms of price, size, complexity, and 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 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 had its difficulties at the beginning. The students were required to progress significantly in relation to their previous laboratory approaches, and any 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 that were developed by this approach.

In order to expand the students' exposure to the practical application of knowledge and to utilize their creativity, a two-semester long, open-ended project was used which required the students to use creative approaches in order to find a problem's solution. 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 that involved the writing of a report and an oral presentation.

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