Improving Data Acquisition and Reduction in a First-Year-Student Laboratory Experiment

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Abstract

The College of Engineering at The Ohio State University requires all engineering students to complete introductory courses in engineering as part of their academic experience. The courses are usually taken during a student's first year and follow either a standard two course track or an honors three course track. Courses in each track have both lecture and hands-on laboratory components. For the second course of the standard track, four-member-teams of students must design and build a roller coaster as their 10-week lab project. One supporting experiment requires the acquisition of voltage and time data on two channels. An off-the-shelf virtual oscilloscope instrument had been used to acquire time data, but its use resulted in an operational bottleneck in the lab. It took students too long to learn or relearn the virtual tool, and too long to acquire, read-off, and notate time data. To help resolve the problem, an on-purpose data acquisition and reduction computer program was written in the LabVIEW™ graphical programming language and was implemented on laboratory computers. Also, to further help in time management and data processing accuracy, tables of geometric values were developed for each apparatus. This paper describes the old and new methods of data acquisition and processing as used in one lab experience in support of the student-team roller coaster design process. It presents an assessment of the effectiveness of the new method relative to the old, and shares information regarding future efforts to improve student experience with laboratory data acquisition and reduction.

Background

Data acquisition and reduction concepts can be difficult to understand for even a seasoned experimentalist. And providing a satisfactory learning environment for first-year college students can be a truly challenging process, especially if the data processing is not the main object of the experience.

An approach taken by The College of Engineering at The Ohio State University requires all engineering students to successfully complete one of two possible tracks as an introduction to engineering; a standard track of two introductory courses or a more challenging honors track of three introductory courses in engineering. A track is usually selected and taken during a student's first year, and both include the use of lecture and hands-on laboratory components.

The primary objective of all the introductory engineering courses is to provide an environment that enables the first-year student to learn enough about engineering, early in the student's academic experience, to determine if engineering suits the student. This objective results in a curriculum encompassing broad overviews of engineering disciplines and supporting functions. In the standard track, the approach puts data acquisition and reduction as a supporting function and affords little time to its details. Consequently, the students are exposed to data processing as a 'black box' element in the overall lab procedure. This situation is further reinforced by the use of off-the-shelf virtual instruments which insulate the student from much of the data acquisition details. The honors track courses have more class time and can afford discussions in more depth than the standard track courses; and problems can be more thoroughly addressed. One might speculate that the largely broad approach in the standard track would lead to poor results. However, as shown by Fentiman [(1)] et al, and Merrill [(2)], and Demel [(3)] et al, the approach seems to satisfy the primary objective concerning retention of engineering students at The Ohio State University. Demel [(4)] et al, illustrate the approach is working specifically for honors students as well. All the authors indicate that students are learning in the provided environment.

However, any disruption in the classroom can detract from a good learning environment and negatively impact the learning process. In the hands-on laboratory environment, detractions seem to occur regularly. The lab 'glitch' may be related to apparatus, or computer hardware or software, or to any number of human interactions. A case in point is the operation of one particular student lab in a course in the standard track that has been negatively affected by past choices in computer software and lab procedure.

Introduction

In the second course of The Ohio State University First-year Engineering Program standard track, four-member teams of students must design and build a roller coaster as their 10-week lab project. Student teams are required to include certain features in their roller coaster designs, and must develop a paper design which is reviewed by instructional staff. Each roller coaster is then built from a kit of standard issue parts, and each team is graded on the design and performance of their roller coaster.

The students experience four formal lab sessions in support of their design process. But Lab 2 – finding static and rolling friction coefficients using energy concepts – is relatively more demanding than the other three labs in its requirement for data acquisition, data reduction, and data management. And logistically, Lab 2 requires the student teams to rotate to three different lab apparatuses on different lab tables in a three-table super-group arrangement. A super-group is a logical grouping of lab tables; and with nine tables per lab, results in three super-groups per lab class. The three apparatuses within each super-group offer a progressively more difficult lab experience as regards data acquisition and reduction. One experiment requires use of a notepad and a pencil, while the second requires use of a stopwatch, and the third requires a high speed digitizer and computer. Raw data is acquired and managed by the student teams within each super-group, and is shared among all students in a lab class at the end of the lab period or by email. This arrangement allows the students to obtain and process data from more apparatuses than could otherwise be obtained, for example, from a single-station-per-team approach.

Presenting first-year students with this somewhat challenging lab procedure resulted in a lab-room time management problem and in data inaccuracies. Most importantly, many students could not complete the lab procedure. Analysis of anecdotal data from lab instructors revealed a bottleneck was regularly occurring during the third of the Lab 2 experiments, one that uses a loop apparatus. The team rotation scheme was continually disrupted by waiting for those students at the loop station to finish, i.e., students at other stations finished in much shorter times. Because student teams rotated to different tables in their super-group, the two teams at other apparatuses would switch between their tables and still might have to wait for students at the loop station to finish! This was an unacceptable situation that had to be changed.

The Experiment

During their initial paper-design phase, students are required to estimate the performance of their roller coaster, and demonstrate knowledge of the basic physics principles involved by calculating the speed of a given 'coaster car' (a single 25.4 mm diameter nylon ball) at various stations along the coaster track. To assist in this requirement, each super-group during Lab 2 is provided apparatus of differing loop geometry. A typical loop apparatus, shown in Figure 1, is used to find the effect of centripetal acceleration on the energy losses to a 'coaster car' ball. The apparatus track is formed by parallel rails of ¼ inch (6.35mm) polyethylene tubing that are held laterally to ¾ inch (19.05mm) separation by custom designed 'snap-fits'. The snap-fits mount to slots in wooden ramps, and attach with plastic straps and thumb screws to a loop frame. The loop frame is made from poly-vinyl-chloride (PVC) plumbing pipe and fittings. Ladder towers made of wood support the ramps and allow for different ramp inclinations. Two speed-traps are incorporated, one each, at the loop entrance and exit. Each speed-trap, as shown in Figure 2, has two cadmium sulfide photocells with supporting custom electronics (not shown) to sense the passing of the ball. The ball, with ambient room light, casts a shadow across the face of each photocell it passes. The incident light change causes a resistance change in a photocell which is conditioned and wired to set an electronic flip-flop upon ball entry to a speed-trap, and later

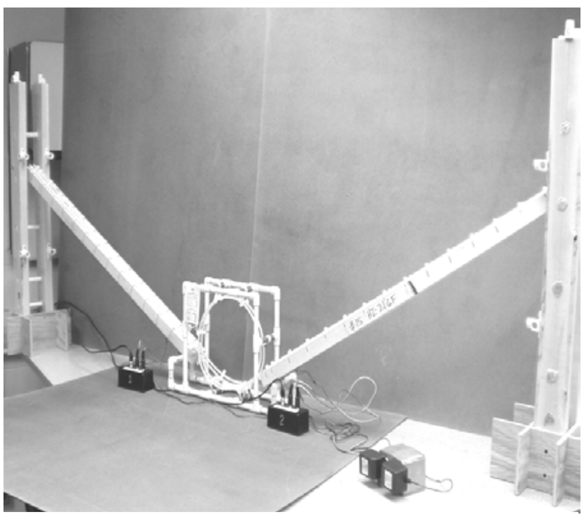

Figure 1. Loop Apparatus

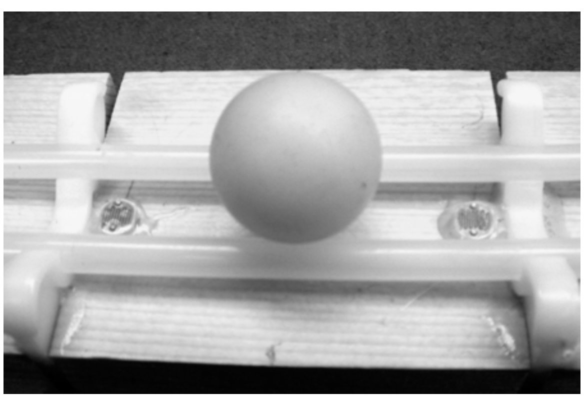

Figure 2. Ball and Speed-trap Sensors

in a second photocell which causes a reset of the flip-flop upon the ball exiting the speed-trap. The outputs of the flip-flops, one associated with the loop entrance and one with the loop exit, are wired to a National Instruments NI5102 High Speed Digitizer installed in a Windows XP™

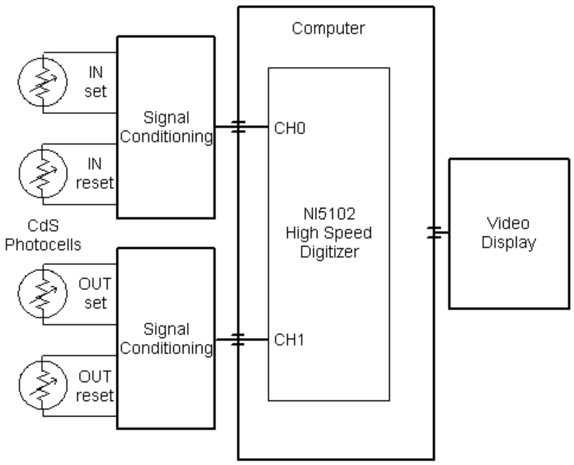

Figure 3. Speed-trap Sensing System

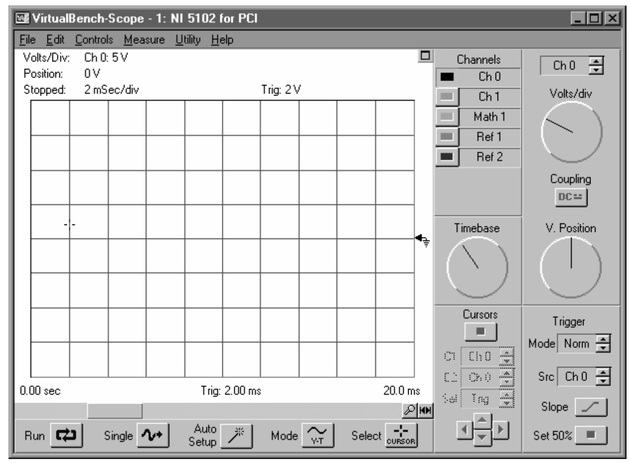

Figure 4. 'Old' Virtual Instrument Panel

driven computer. The NI5102 has two-channel, 8 bit, 20 Megahertz functionality and, as shown in the schematic diagram of Figure 3, the 0 to 5 volt output from each speed-trap signal conditioning circuit is fed to a channel of the NI5102. The voltage data are processed by a proprietary virtual oscilloscope application and displayed on a computer monitor (Figure 4). Students use the cursors function of the virtual instrument to pick the pertinent time tags. The resulting pulse widths are the time of ball travel through each respective speed-trap. The time interval between the pulses is the time of ball travel through the loop (from trap to trap). The trials are repeated three times at each of three starting positions, resulting in nine sets of times. By knowing the distance between photocells, the distance between the midpoints of the speed-traps, and the time of ball travel associated with each, a student can find the ball speed into the loop, out from the loop, and an average speed through the loop. With certain additional geometric values (measured by students), energy calculations can then occur which result in energy loss coefficient as a function of centripetal acceleration. Students can use the information to evaluate choices made in the design process.

The Problem

There were two main problem areas to be addressed; the software application, and the necessary geometry for data reduction.

The software application presents a panel resembling a 'real' oscilloscope and is essentially a general purpose virtual oscilloscope. The general purpose nature of the instrument allows flexibility, and does cause the students to learn something about oscilloscope usage. The interface panel appears somewhat intuitive. However, although the panel itself may be intuitive and was generally no problem to use, the functionality of some features caused angst for the staff and students. Problematic 'features' included:

- a trigger function that scaled improperly and sometimes did not work,
- a settings file load function that needed to be executed twice to do its job,
- a cursor selection feature affectionately known as the 'coarser' feature, and,
- a 'lock-up' occurring sometimes when settings were changed while the instrument was in 'run' mode.

The above list is not exhaustive, but does illustrate that students and instructional staff could have trouble when dealing with the virtual instrument. Various workarounds were developed to deal with some of the problems, but only after the loop apparatus portion of the Lab 2 procedure was developed did the problematic nature of the virtual instrument really become evident. The failure to trigger on occasion and the need to use cursors to select the tag points for time difference calculations were the two greatest time consumers.

The second problem area was the geometric measurements needed for data reduction. The procedure called for students to take measurements of the apparatus geometry. Too much time was required to perform the measurements. A different approach was necessary.

The Options

Further checking with instructors revealed that if the data processing for the looping apparatus was partially automated, and if some necessary geometric values were provided in tabular form (rather than requiring student measurement), then the students should be able to finish the procedure within the given lab time limits and would have better results with the data processing.

The geometric measurements issue could be addressed by simply giving the students the necessary values rather than having them make the measurements. This approach would not impact overall technical objectives, and would 'speed things up'.

It was noted that the virtual instrument could write its channel contents to a text file. The students could dump the data to a .txt file, import it into a spreadsheet, isolate the data of concern, and calculate the necessary time differences. However, the virtual instrument's settings would change when the channel contents were written to a file! The settings would have to be reloaded after each trial. This behavior made the option useless; the distraction to learning would be too great, and too much time would be used to reload the settings after each trial. And also, there were just too many data points to process in such a manual mode.

What about a different software product that would work with the NI5102? Individuals contacted at National Instruments could give no leads to an inexpensive alternative. Web searches turned up nothing useful for this case.

With so many issues surrounding the virtual instrument software, maybe a custom, in-house developed program could do a sufficient job. It might take a while to develop but could be used over many academic quarters. And it could be programmed on-purpose for just this one experiment, making it simpler and potentially easier to use. It could be programmed to display and save the necessary data that the students could directly use. Also, no new hardware would be required. A completely new computer program, to interface the user to the NI5102 and to partially process the data, would be necessary for this option.

The Solution

A graduate student was tasked with measuring apparatus geometry and creating values tables. It was a straightforward process that resulted in small laminated cards that displayed the geometric values for each loop apparatus. Respective cards could be attached to each loop frame.

Within four workdays after deliberations on the data acquisition and processing issue, a custom computer program had been designed, written in the LabVIEW™ graphical programming language, and was operating. Additional input from staff regarding application features resulted in minor changes. Also one obscure bug, that showed itself only if a certain sequence of events occurred, was found and eliminated.

The solution involved only new software; the same hardware was used. The user interface was designed for easy use, for minimal but effective data processing and presentation, and for easy code modification. Figure 5 shows an example of the graphical programming language; a programmed code segment that handles data file management. The icons are analogous to lines of text code or functions, while connecting lines direct the data flow.

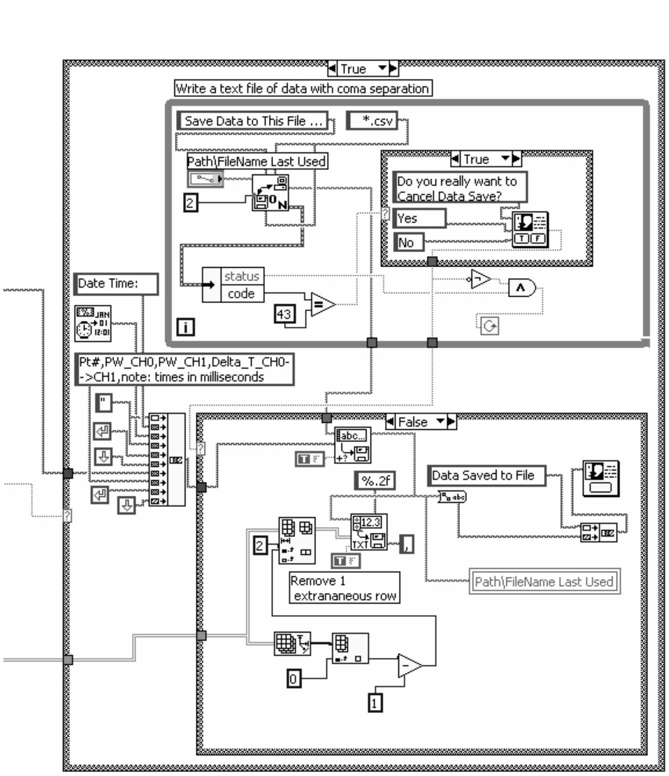

Figure 5. Code Segment

The full color panel for the new user interface is shown in grayscale in Figure 6. Control buttons enable a data point to be taken, cause a data sequence to be ended, allow the saving of data to a file, and cause the application to stop. A graph of the sampled voltage data and also the necessary calculated time intervals are displayed. A data point counter, sequence counter, and last path/filename are each displayed for convenience. The user can enter one line of descriptor and is given error message and status information in a dialog box. A 30 second timeout feature, i.e., a time window within which a trigger must occur, is included to prevent infinite waits for a data trigger. The experiment requires three times, i.e., two pulse widths and one interval between pulses. Since the possible range of values for each time was known, the software was programmed with a constant time base (50000 samples per second) and a static channel buffer size (50000 simultaneous samples per channel). This resulted in a one second sampling window with 20 microsecond resolution; thereby allowing for all normal scenarios while minimizing the need for more controls.

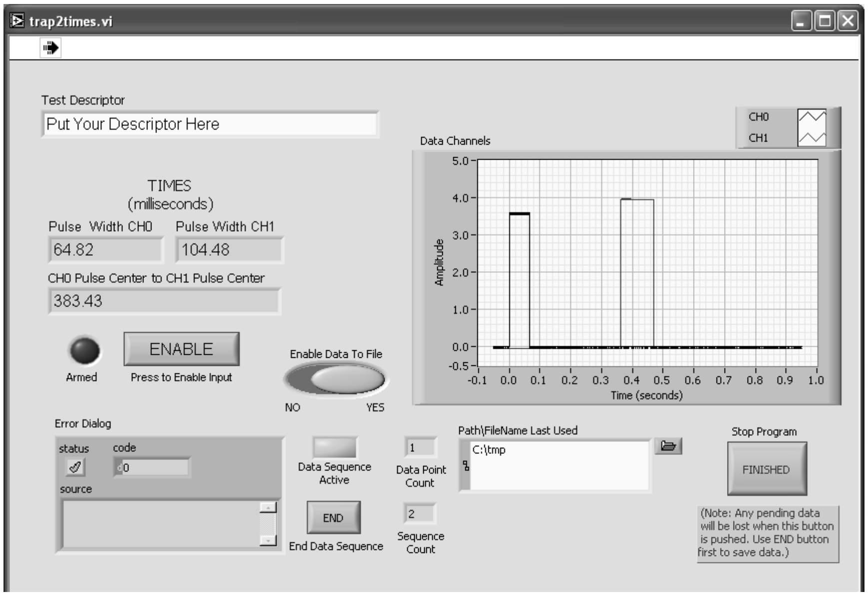

Figure 6. New User Interface Panel

To start-up the application, a user simply double-clicks an icon. The application is already active when the panel appears, and it waits for an input from the user. The user can enter a run note and can select whether to save data to a file (the default is to save data to a file). The user can then enable a data point to be taken by pressing the “ENABLE” button. This action arms the application as indicated by the “Armed” light. A CH0 signal transiting in a positive direction through the 10% level of the vertical range will cause the NI5102 to take a data burst and transfer that data to a data array and to the graphical display. If the data is valid, the data is written to the data file (if selected) and the data point counter is incremented. If a timeout occurs or if two pulses (one each channel) did not appear in the data burst then an error message is displayed and any data from that event is discarded. The user can repeat the data enable process as many times as necessary. When no more data points are required, the user presses the “END” button to end the data point sequence and increment the sequence counter. When the user has no more data to acquire, the “FINISHED” button can be pressed to stop the application. If data was saved to a file (or to more than one file) then the user can now import the data to a spreadsheet or other application. To start the application again, the user simply presses the run control/ indicator arrow (located at the upper left corner of the panel).

Results and Conclusions

The new application was demonstrated to faculty members and positive reactions resulted. The new geometry values cards were approved and attached to all loop apparatuses. The Lab 2 procedures document was amended to include the new virtual instrument application. A go-ahead was given for full implementation with winter quarter 2005 (beginning January 3, 2005) being the earliest the new method could be used in actual lab classes.

The new methodologies for Lab 2 were used by approximately 80 four-student-teams. Lab activities during each class period were observed by the author. A few impromptu, very casual and brief interviews were conducted with students during the lab classes. Also, instructional staff members were asked for feedback on their lab experience, including comments on student lab reports. Most staff feedback was via email messages, while some was given during a weekly staff meeting. Some staff chose to voice comments informally during an impromptu office or hallway meeting. No other assessment was performed which might have delineated, for example, the effect of improved instructional techniques, classroom management style, or other possible influences on the results.

Feedback concerning the apparatus geometry information tables was immediate. During the first lab session, it was discovered that the necessary physical characteristics of the coaster ball were missing from those tables. To deal quickly with the omission, an errata sheet was placed at each loop apparatus station. Later, new tables were generated to replace the originals.

Some students were confused by the data-saving feature of the new virtual instrument. The written lab procedure prescribed appropriate steps which, if followed, would result in proper operation of the feature. An interview with one team revealed they had not followed the procedure; they had developed their own (incorrect) ways of using the instrument. Another team thought that simply entering a file name into the displayed name box was sufficient to cause data to be saved to a file of that name.

A review of lab summary worksheets showed a significant result; 97.5% of the student teams finished all the in-lab procedures. Some teams finished mandatory in-lab work and left the lab minutes before the regular end-of-class. A few teams went as much as ten minutes past the regular end-of-lab time. Most teams finished and left the lab ahead of or on time. This compares to previous anecdotal information of about 7 in 9 student teams completing the in-lab procedure, even if instructors made impromptu changes to accommodate an anticipated time overrun. Additionally, the worksheets revealed that the loop apparatus data was much more consistent across labs sessions and was more accurate than previously obtained data sets. This result is attributable to the elimination of cursor selection (i.e., student selection) of time tags, and replacement of that functionality with an automated, higher resolution determination of the required times.

There were no reported malfunctions of the instrument as regards proper triggering for data acquisition. There was only one reported incident concerning data acquisition wherein a photocell was improperly connected, resulting in an 'irregular trace' for the CH1 signal.

Feedback regarding lab reports was not directly related to the new virtual instrument. But some graders, with reference to loop apparatus off-line data post-processing, speculated that students generated their reports without really thinking about the meaning of it all. The assumption being that students 'blindly' processed the data as outlined in the lab procedure, leading to 'unnoticed' errors in some students' final results.

Remarks from various staff members conveyed a level of satisfaction with the overall results in their respective lab classes:

One instructor replied, "The main problem with the new interface *{new virtual instrument}* was *(students)* over-saving *(data)*; I eventually just gave up and let them go ahead … the interface is a major advance over the old way. The only data problem I saw was with a team that didn't understand the distance between photocells and therefore got strange answers".

And a graduate teaching assistant replied, "The lab2 went great for my session except we ran out of time a little bit. But since we are the last session in lab that day, it did not cause any problem. The new virtual instrument worked for the loop apparatus experiment and is much more convenient than the one we used before. It has clear graphic display of the signals and the digital reading of the time duration is given so no cursors were needed for students to figure out the values. Good job!".

And another, "As for feedback, this new interface was great! There were no significant problems except funny looking/absent traces when the sensors were not cleanly connected. And … a few students had trouble recording…times *(un)*til I told them where to look. That was probably just inattentiveness on their part though. Overall things went pretty well".

And, "The virtual instrument was excellent. It was so simple in fact there was some confusion because the *(time)* answers are presented right there in the interface, some students thought some post-processing was necessary".

And finally, "The o-scope software *{new virtual instrument}* was fine for the most part. I had one group reporting that they saved it *{data}*, the display said saved to c:/tmp. but there were no files in that directory. So I am not sure what that was all about. Other than that, I think the software is a huge improvement because nothing needs to be done other than push a few buttons".

Although no staff commented directly about their relative stress level, the author observed a generally calm atmosphere in all lab sessions. This was a contrast to previously observed Lab 2 sessions; where staff would be somewhat consistently occupied with problems, usually related to the data acquisition at the loop apparatus stations.

As reported by instructional staff, the new virtual instrument was an improvement to their lab experience. Generally, if the staff perceives an improvement, the students have benefited both directly and indirectly. Directly, because there are fewer distractions to the students' learning process; and indirectly, because the staff is less stressed and more able to effectively maintain an environment for learning.

Future Efforts

The new software was designed with the idea that simple modifications to the code would make it useful for other lab procedures. For example, the first course in the standard track has two lab procedures that require the acquisition of voltage pulses at much different time scales. The new software could be easily modified and used on-purpose in those two labs. By using a proven and familiar computer application in many of the first year engineering lab experiences, students would benefit by the familiarity with the tool, by the uncomplicated direct application of it, and by its ease of use.

The success in using the LabVIEW™ graphical programming language has led to discussions about developing a sensors and data acquisition course with LabVIEW™ as the principal programming language. National Instruments has already granted some equipment to The Ohio State University College of Engineering to help in establishing such a course. The course will initially be offered as a technical elective to honors students with the intent to broaden the admissions criteria as resources allow. The curriculum will be developed with distance learning in mind, as the hardware and software to allow lab experiments to be remotely performed are already available. This approach would allow very large classes to be served.

Summary

To overcome operational and technical problems, a new approach to the data acquisition and data processing in support of a first-year student laboratory experience was developed and implemented for an introductory engineering course at The Ohio State University. During a single work week, a new data acquisition application was developed to acquire data from the loop apparatus of Lab 2. This development, along with a different approach to handling apparatus geometry information, led to the piloting of the methodology in an actual student lab room setting.

The efforts to develop the new methodology were well spent. All but two student teams finished Lab 2 during the allotted time. The raw data was more consistent and more accurate than previous methods provided. There were no reports of virtual instrument failure-to-trigger; a significant problem with previous software. And the staff feedback regarding this change was all positive.

Experience in this process has led to efforts to use the new methodology in other lab procedures, and to discussions towards the development of a new course in sensors and data acquisition and reduction for engineering honors students.

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Biography

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Michael Hoffmann is an Instructional Laboratory Supervisor at The Ohio State University. After more than 20 years in research and industry Mr. Hoffmann is now one of two individuals responsible for laboratory facilities within the First-Year Engineering Program in the College of Engineering, where in part he develops laboratory experiments and laboratory instructional materials for over 1000 students in the Program. His credentials include earned B.S. and M.S. degrees in Aeronautical and Astronautical Engineering from The Ohio State University.