

# Introducing Instrumentation and Data Acquisition to Engineers using LabVIEW

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## Abstract

For several years, LabVIEW has been used within the Department of Mechanical Engineering at the University of Strathclyde as the basis for introducing the basic concepts and practice of data acquisition, and more generally, instrumentation, to postgraduate engineering students and undergraduate project students.

The objectives of introducing LabVIEW within the curriculum were to expose students to instrumentation and experimental analysis, and to create courseware that could be used flexibly for a range of students. It was also important that staff time for laboratory work be kept to manageable levels. A course module was developed which allows engineering students with very little or no previous knowledge of instrumentation or programming to become acquainted with the basics of programming, experimentation and data acquisition. The basic course structure has been used to teach both undergraduates and postgraduates as well as laboratory technical staff.

The paper describes the objectives of the use of LabVIEW for teaching, the structure of the module developed, and the response of students who have been subjected to the course, and how it is intended to expand the delivery to greater student numbers.

## 1. Introduction

Laboratory work within university engineering departments is expensive, both in terms of the finance required to run laboratories and their equipment, and in terms of staff and technician time. This situation has been exacerbated in the UK by the rapid recent increase in student numbers. As a result, there has been a gradual reduction in the exposure that students get in experimentation, and a move towards computational methods. It is clear, however, that engineering students should have knowledge of the role that experimentation plays in modern engineering practice, and engineering departments should expose students to modern data acquisition techniques.

For several years, LabVIEW has been used within the Department of Mechanical Engineering at the University of Strathclyde as the basis for introducing the basic concepts and practice of data acquisition, and more generally, instrumentation, to postgraduate engineering students and undergraduate project students. The number of students using LabVIEW has gradually increased. Currently, all students have experimental rigs demonstrated to them at 2<sup>nd</sup> year level with a focus on the data acquisition systems: these range from simple chart recordings, through systems based on programs written in the C programming language, to recent systems built with LabVIEW. In addition, final year project students with an experimental project, and postgraduate students, follow an introductory course based on LabVIEW. It is the intention that all mechanical engineering students should have a basic knowledge of modern data acquisition with hands-on experience. An additional benefit is that students are then also introduced to concepts of programming. Although mechanical engineering students were formerly given instruction in programming, this is no longer the case. The graphical programming environment of LabVIEW has proven to be a suitable teaching mechanism for students to understand basic concepts of loops, case structures, etc in a short period and to generate working programs.

As the result of being a long-standing traditional department, the laboratories contain a large variety of experimental rigs. These have a variety of data acquisition systems, ranging from manual reading from gauges, through simple chart recordings, to the use of specially written computer programs in Basic or C programming language. With regard to the computer programs, it was generally found difficult to maintain the programs when the program author had left, largely due to the obscure low level calls to the A-D cards that were embedded within the programs. In 1995, the Energy Systems Division of the department therefore decided to standardise on LabVIEW for data acquisition, and this is gradually permeating through the whole department. There were clear benefits to be derived from standardising on one software package, and LabVIEW was selected after a review of the available software packages.

The objectives of introducing LabVIEW within the curriculum were:

- a) to expose students to modern instrumentation and experimental analysis;
- b) to create courseware flexible enough to be used by a range of students (postgraduate, undergraduate, technical staff);
- c) to develop courseware that takes advantage of the comprehensive nature of LabVIEW to provide applications across a wide range of engineering disciplines; and
- d) to ensure staff time required for laboratory work is kept to manageable levels.

A course module was developed which allows engineering students with very little or no previous knowledge of instrumentation or programming to become acquainted with the basics of programming, experimentation and data acquisition. The module was designed as a mixture of lectures, tutorials and practical work, but with the emphasis on self-learning. The basic course structure has been implemented:

- a) for groups of Faculty PhD students working on industrial Postgraduate Training Partnership projects (working with the National Engineering Laboratory at East Kilbride, near Glasgow);
- b) as a module within a postgraduate Master's taught course;
- c) for final year undergraduate project students who undertake a major final year experiment-based project; and
- d) as a Continued Professional Development module for laboratory technical staff to appreciate modern data acquisition software.

The following sections describe the structure and content of the module developed, and the experience gained from tutors and student feedback. In addition, a description is given of other uses of LabVIEW in the department, particularly with respect to final year project student work.

## **2. Course Structure and Content**

The course has been developed to be flexible, so that it can be followed by students with different levels of experience and ability. The target students are predominantly mechanical engineering students, although students from other engineering disciplines have also followed the course. The focus is not on giving the students a detailed knowledge of instrumentation, but purely a means of enabling them to understand the basic concepts, and to give them a starting point for developing the data acquisition systems and analysis procedures they may need in their own project work (or indeed, in future industrial or research jobs).

In essence the students should:

- understand the underlying capabilities and structure of a state-of-the-art PC-based data acquisition system;
- be able to select and run existing library programs for data gathering and analysis; and
- be able to write or modify simple programs for acquiring, processing and storing data.

Table 1 sets out the course structure in its most commonly used form - as an intensive one week module.

### **Measurement Systems - Syllabus**

*Monday 18 Jan to Friday 22 Jan 1999*

**Staff Involvement**

P Strachan, A. Oldroyd, M. Stickland

<b>Course Structure</b>	5 days @ 6hrs/day; lectures: 6 hours; practical laboratory work 24 hours. Students expected to work outside formal contact times.
<b>Laboratory Description</b>	A large part of the course will be undertaken in the computer laboratory for the student using data acquisition software as a 'virtual' laboratory. There will be two experimental exercises
<b>Main Text Books</b>	E.O.Doebelin, "Measurement Systems: Application and Design", McGraw-Hill, 4th Ed, 1990. LabVIEW Student Edition (on temporary loan during classes).
<b>Overview and Aims:</b>	The use of computer-based data acquisition and processing systems is now routine for experimental engineering applications. The aim of this course is to introduce the student to measurement systems by considering transducers, calibration and data acquisition requirements. The particular focus will be the use of state-of-the-art virtual instrumentation software, LabVIEW. By the end of the course the student should understand the procedure and necessary considerations for obtaining experimental data and be familiar with current software for data acquisition and processing

<b>Time</b>	<b>Topic</b>
Mon 9:00-11:00	Introduction and course overview: (the measurement system, reasons for measuring, active and passive transducers, analogue and digital signals, examples of system implementations.) Demonstration of LabVIEW.
Mon 11:00-12:00	Computer lab - LabVIEW tutorial
Mon 14:00-17:00	Computer lab - LabVIEW tutorial
Tues 9:00-12:00	Computer lab - LabVIEW tutorial
Tues 14:00-15:00	Lecture: Sensor and instrument specifications, noise, errors and calibration
Tues 15:00-17:00	Computer lab - LabVIEW tutorial
Wed 9:00-10:00	Lecture: Transducers for temperature measurement (temperature, heat flux and radiation sensors. calibration and standards.)
Wed 10:30-12:00	Experiment. Write LabVIEW program to acquire data from pressure, temperature and volume sensors, then to process and analyse the acquired data.,
Wed 14:00-17:00	Continue with experiment and program development and testing
Thurs 9:00-10:00	Lecture: Transducers for flow measurement (orifice plates, hot wire anemometry, flow visualisation, particle image velocimetry.)
Thurs 10:30-12:00	Demonstrations: wind tunnel experiment, combined heat and power rig etc
Thurs 14:00-17:00	Computer lab: LabVIEW program development for hot wire anemometry experiment
Fri 9:00-12:00	Computer lab: LabVIEW program development for hot wire anemometry experiment. Test program to acquire calibration data.
Fri 14:00-17:00	Continued program development and testing program on laboratory rig.

Table 1: Example syllabus for instrumentation course based on LabVIEW

The important features are:

- Background lectures on the components of a data acquisition system.
- An initial demonstration of LabVIEW to introduce the basic layout and concepts of the programming environment.
- Self-learning of the programming environment through the use of tutorials.
- Two experiments for which the students write their own programs - the first a simple experimental test rig, the second a more complex rig. A key consideration in the selection of the experiments was to provide flexibility, i.e. to enable students to either write a simple program to achieve the objectives, but with the possibility for extended targets for more able or advanced students.
- Demonstration of data acquisition software applications on a variety of experimental rigs.
- Additional lectures covering common sensors and fundamentals of instrumentation (e.g. sampling and aliasing). This can be changed or extended if the students are likely to use other sensors e.g. for the measurement of pressure, strain, or vibration.

The course structure was extended to MSc students who received a course module on instrumentation. This contained more detail at each level, but used essentially the same structure.

### 3. Experimental Rigs

The selection criteria for the experimental rigs were as follows.

- They should provide a range of complexity from simple acquisition of pressure and temperature signals through to more complex systems requiring control.
- It should be possible to set more complex analysis tasks for more advanced and able students.
- They should demonstrate common mechanical engineering experiments.

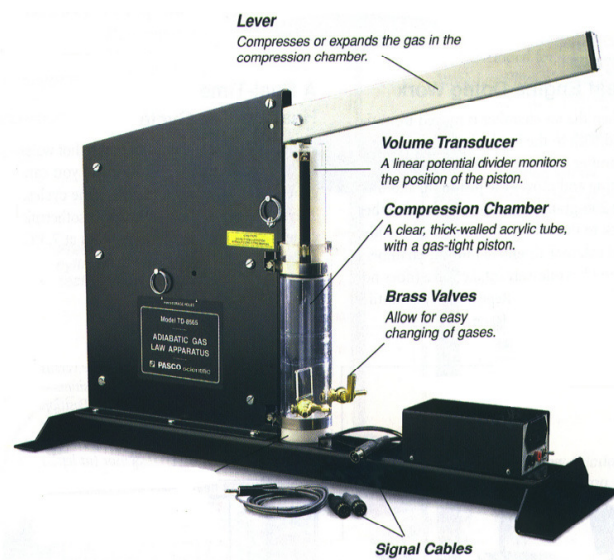
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The two rigs selected were an adiabatic gas law apparatus and a flow experiment using hot wire anemometry. In both cases, the rigs could be used at different levels: from letting students simply run an existing program and observe and comment on the data acquisition system through to students writing programs from scratch to undertake the data acquisition and analysis.

### 3.1 Experiment 1: Adiabatic Gas Law Apparatus

The students are given an instrumented piston-cylinder device which has a manually operated piston which, when displaced, will either compress or expand the gas contained within the cylinder adiabatically, **figure #**. The cylinder is instrumented with the following devices:

- Pressure transducer
- Temperature transducer
- Linear displacement transducer



**Figure #, Pasco adiabatic gas law apparatus.**

The data acquisition system consisted of a PC with an analogue to digital converter (A/D) card. The signals are all conditioned to the range from 0 to +5V before being wired into the card. [Expand?]

The students are given the calibration coefficients for the three measurement devices and are asked to write a data acquisition program that will record the variation in output voltage from the pressure, temperature and displacement transducers. When the data is recorded they are asked to convert the raw data to engineering data and then display the time-varying data from the three sensors. This is the minimum requirement. Students are asked to use additional time to progress the analysis to select the adiabatic compression part of the experimental data, and calculate the gas constant, then to calculate the work done during the compression.

The students are given a laboratory sheet describing the experiment and the sensors. They are given wiring instructions. They have already followed the student tutorial on graphical programming, so the only additional information they are given is on the analogue input VI and its required inputs.

Tutorial assistance is given to the students as required to enable them to get a working program. The following VI is a typical front panel display. At the end of the time allowed for this part of the course, students are shown a complete program for those who have not completed the extended analysis.

[Diagram of VI]

This first experiment enables the student to test their ability in using a data acquisition system to acquire raw data and, given the calibration coefficient to turn the raw data into engineering data. The analysis of the data is limited but does allow the student to present the acquired data graphically and to recognise that the experimental raw data can be post processed to form meaningful information.

Regarding specific learning outcomes, at the end of this experiment, the students have:

- worked with simple measurement of temperature, pressure and displacement;
- written a simple program to acquire, process, analyse and display data (and therefore developed a “complete” data acquisition system);
- demonstrated the adiabatic gas law.

### 3.2 Experiment 2: Hot-wire Anemometry

In this experiment, the students are required to acquire data from a constant temperature hot wire anemometer bridge circuit, to calibrate the transducers, to carry out an analysis of the transient signals, and, optionally, to control a stepper motor driven traversing system using the D/A function [??] of the card mounted in the PC.

The output of the hot wire anemometer bridge is dependent upon the speed of the air blowing over the hot wire probe and is non-linear. The bridge circuit may be seen in figure # with the hot wire probe represented as the resistance,  $R_w$ , and the output as the voltage,  $E$ . A typical calibration curve of voltage,  $E$ , against wind speed,  $V$ , may be seen in figure #.

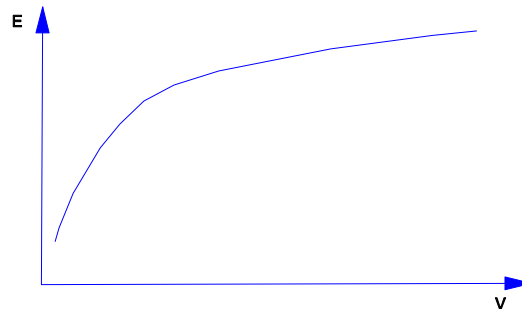
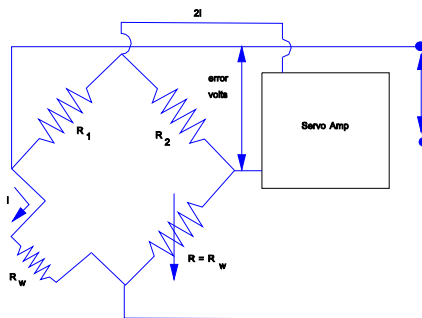


Figure #: Hot wire bridge circuit

Figure #: Hot wire calibration curve

The probe is calibrated by placing the probe in the jet issuing from a convergent nozzle fed by a plenum chamber attached to a high pressure air supply, figure #. The total pressure in the flow can be measured by an inclined manometer attached to a static pressure tapping in the plenum. The pressure in the exit plane is atmospheric and hence the velocity in the exit plane can be calculated from Bernoulli's equation. The students record the variation in bridge output with air speed and create a calibration curve of air speed against bridge output. The students then fit either a polynomial or power law equation to the data set and produce a calibration which may be used by the data acquisition system to convert from raw to engineering data.

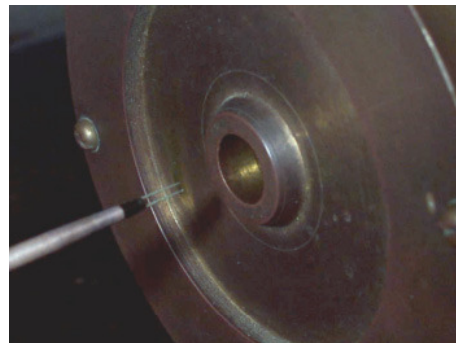
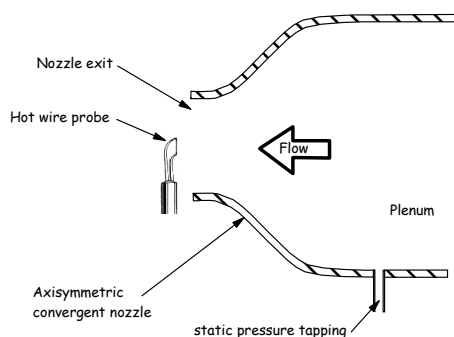


Figure # Hot wire calibration rig

Figure #, Photograph probe in calibration rig

When the calibration is complete the students are required to undertake one or more of three experiments with the hot wire probe.

**Jet traverse:** The students traverse the calibrated probe along the length of the jet to analyse how the jet decays over a distance. This allows the student to plot a simple graph of velocity against distance, figure #. The traverse is carried out manually.

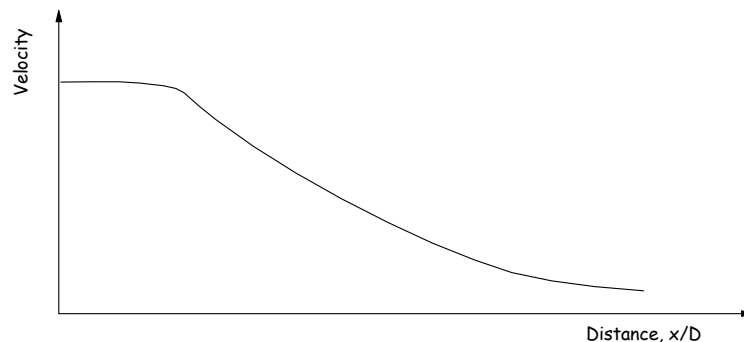


Figure #, Axial jet traverse.

**Vortex shedding:** The student places the hot wire anemometer downstream of a circular cylinder and uses the hot wire probe to measure the transient flow field in the cylinder's wake. When the data has been acquired the student may plot the variation of velocity with time and recognise that the flow field is highly transient. The student is then required to undertake a spectral analysis of the velocity waveform in order to identify any dominant frequencies within the wake. This signal analysis yields the frequency of the Von Karman vortex street that is shed by the cylinder. The dominant frequency is then used to calculate the Strouhal number of the flow and it is compared with the published value for the cylinder.

**Wake traverse:** The hot wire probe is traversed across the wake of a two dimensional wing section in a small wind tunnel. The probe is traversed by a stepper motor driven traversing rig, which is controlled by the data acquisition system via the A/D card. As the velocity at each point across the wake is recorded, the total loss in momentum within the wake can be calculated and the drag force and hence the drag coefficient of the section determined and compared with published data. The student is also asked to undertake a spectral analysis of the wake in order to determine whether there are any dominant frequencies within the wake or whether it is just random turbulence.

[Example VI] – standard and one written by student?

Regarding specific learning outcomes, at the end of this experiment, the students have:

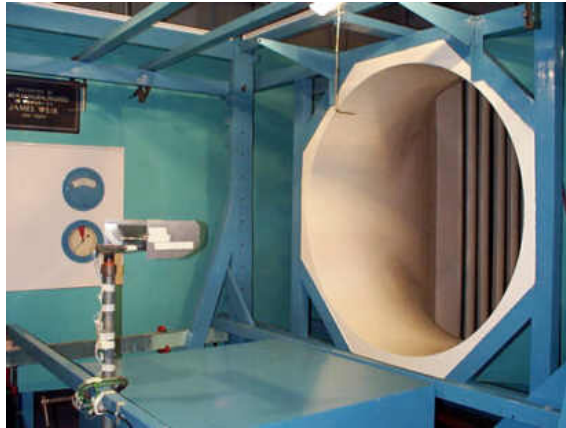
- undertaken calibration and realised its importance;
- written programs to acquire, process, analyse, save and display data (the level of analysis can be tailored from simple to complex);
- written programs with a control function (optional extension);
- observed turbulence and understood how it can be measured and analysed.
- written a laboratory report focusing on the experimental configuration and data acquisition and analysis.

#### 4. Data Acquisition Demonstration Rigs

An important element of the teaching is to show modern data acquisition systems applied to a variety of rigs. Over the last few years, a number of rigs have been developed, or modified, to LabVIEW-based systems. The following summarises the rigs which are demonstrated to students.

##### Wind Tunnel

For the wind tunnel demonstration, the 5 foot (x metre) diameter open working section closed return tunnel within the University of Strathclyde is used. A NACA 2412 aerofoil section is pressure-tapped and fixed in the tunnel (fig).



*fig : University of Strathclyde Wind Tunnel showing a sting mounted model*

The pressure taps from the working section are fixed to a 20 port Scanivalve and is in turn connected to an electromanometer pressure transducer that converts the pressure to a voltage in the range of  $\pm 2V$ . The voltage signal is then fed into a PC via a National Instruments AT-MIO16 card. Another electromanometer is used to monitor the wind tunnel free stream velocity and the aerofoil pressure taps are connected to a multi-tube inclined manometer as well as the Scanivalve. The system is then used to obtain pressure data and hence calculate the lift and drag coefficients for the object under test. The pressure data is displayed on a graph and then compared with the inclined manometer readings.

The demonstration shows the use of data acquisition in acquiring and analyzing data, the control of other equipment via digital outputs and the speed of the system in acquiring data in comparison to the old traditional method as demonstrated by the multi-tube manometer.

The system is also used to measure aerodynamic forces on a test object using a 2-component strain gauge balance connected to the PC via a SG-2413 add-on card, This is a developing project.

### **CHP**

The small scale Combined Heat & Power (CHP) unit demonstrates how using both electrical power output and heat recovery improves the overall efficiency of the system. The 2- Cylinder Petter diesel engine (fig) is connected to a single-phase, self-exciting induction generator. The resulting electrical A/C output is connected to resistance heaters.

There are two heat recovery circuits. The first is a circuit of the engine cooling water which feeds panel radiators. The second is a multipass exhaust gas-to-water heat exchanger surrounding the engine exhaust, with the heated water flowing through a radiator before returning to the heat exchanger.

For the demonstration, the following sensors have been installed to enable efficiencies to be calculated. Temperature measurements are taken with Type K thermocouple sensors which is attached to a National Instruments SCXI (MODULE NO.) unit. These thermocouples measure the inlet and outlet temperatures for the water and gas flowing through the exhaust heat exchanger and the inlet and outlet readings for the cooling water circuit.

(Turbine Flow Meters) These voltages are fed directly to the AT-MIO card through the SCXI feed through panel.

The Front panel VI is shown in Fig). As can be seen from this figure the system efficiency can be directly calculated from all of the sensor readings, making the system both a good demonstration package for data acquisition learners, but a good energy demonstration that is used for 2<sup>nd</sup> year undergraduate laboratory demonstrations.

### **Ricardo**

The Ricardo engine has been used as a 2<sup>nd</sup> year undergraduate data acquisition and engine cycle demonstration within ThermoFluids for a number of years. The engine is a single cylinder, 4-stroke capable of running on either diesel or petrol cycles by changing the cylinder head. The compression ratio of the engine can also be altered while the engine is in operation. Normal running speed is between 1000 and 3000 rpm.

Recently a project was initiated to update the data acquisition system using labVIEW. A AT-MIO 16 XE-50 card is mated to a SCXI chassis. Measurements are taken from the air flow meter to determine air consumption. Pressure sensors are used to determine the pressure within the cylinder and the crank angle is measured via a photo optic device. Synchronization of the two sensors are provided by a Top-Dead-Centre sensor. Temperature measurements are taken for the cooling water intake and outtake, along with exhaust gas temperature. Hence the compression ratio and efficiency of the engine can be monitored along with the Pressure – Volume diagram, demonstrating and actual 4-stroke cycle to the students.

For the data acquisition course, again the system demonstrates the use of SCXI for reading multiple data inputs that originate from different sensors. Also, the use of external triggering is demonstrated as a means of initiating data acquisition as opposed to the more normal user started process.

### Laser Lab

## 5. Project Work

Table 2 shows a list of current projects that employ LabVIEW. The main stumbling block in these projects is the different levels of computer literacy of some of the students taking the projects. As these projects are primarily treated as the students' own work, the onus is on the student to pick up and use LabVIEW with minimal staff involvement.

Project	Description	Measurements
3-D Strain Gauge Balance	Design, test and build a 3-component strain gauge balance.	Drag, Lift, & Pitching moment
Combined Heat & Power		Flow rates, Thermal & Electrical efficiency
Stirling Engine Instrumentation	Instrument and asses performance characteristics of a pressurized stirling engine	Pressure Temperature and rotational speed
Building materials conductivity	Design and build a test rig to British Standards that will determine the thermal conductivity of building materials.	Temperature
Ducted wind turbines	Using	Pressure Rotational velocity and power output
Small scale jet engine instrumentation		Flow rates, feedback control and temperature

Table 2: current undergraduate projects

To do this a set structure has been devised and implemented which appears to work well with the students. The 1<sup>st</sup> step is to provide the students with access to LabVIEW student edition. This allows the students to get use to the graphical user interface (GUI) LabVIEW employs and to pickup basic programming skills, as programming at present is not offered to mechanical engineering students. The students are given around 2 weeks to do this and are then given the same data sheet as that employed for the other courses. The first task is to get acquainted with acquiring real data, and the PIV rig is used.



## 6. Discussion

The experience of running the course for postgraduate students was that all the students, even though the majority had no previous experience of programming or data acquisition, were able at the end of one week to produce programs to undertake simple data acquisition. Several of these students have gone on to develop and/or use quite complex experimental rigs (with or without LabVIEW). Final year project students also picked up the basic concepts easily, although they followed the course with a greater element of self-learning over a longer period.

All students who followed the standard course outlined above (for the last 3 years) were asked for feedback on whether they thought the structure of the course gave them an good introduction to the basics of instrumentation, and in particular what they thought of the computer laboratories and experimental work.

Their responses can be summarised as:

Even those students not involved in experimentally based projects reported that they found the course worthwhile. Reports were generally positive.

## 7. Conclusions

The primary benefits that the authors have perceived from the use of standardising on common data acquisition software, in this case, LabVIEW, are:

1. Having a common software base means that several academics can understand the data acquisition programs, so the department is not reliant on individuals.
2. An excellent range of analysis functions is readily available.
3. The use of simple acquisition VIs means the student (or academics writing programs) do not have to get involved in low level calls to the data acquisition cards.
4. Simple programs can be written by students, thus improving their ability to instrument test rigs and analyse their results.

Teaching of data acquisition with LabVIEW is not without problems. The size of LabVIEW is often daunting at first, and although Student Editions are used as tutorial material for the programming concepts, it is often difficult for students to find relevant examples. Other data acquisition software may be easier to use, but it is believed that the comprehensive nature of LabVIEW make it better as general purpose software.

For the future, it is planned to extend the teaching of modern data acquisition to all mechanical engineering students, not as a major module, but as a common element at various stages in the curriculum. This will be done:

- a) by gradually updating rigs used in laboratory work through all stages so that students can run pre-set programs to acquire data;
- b) by including data acquisition systems available within design classes;
- c) by including data acquisition lectures and laboratories in undergraduate course where students are introduced to programming/data acquisition.

[To do this requires larger number of workstations to cope with the 120(?) mech eng students in each year, and to have the PC lab bear the main laboratories. how to process all students?

Experience of Electrical Eng in 3<sup>rd</sup> year, give example of how they process large numbers of students??]

[Emphasis on self-learning -web-based exercises - writing of simple DAQ programs and simple experimental rigs...]

[Structure of course as outlined above may be expanded]

## 8. References

LabVIEW, National Instruments...