Work in Progress: Deconstructed Temperature Measurement Lab

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Abstract

This work in progress describes the evolution of a temperature measurement activity. Initially, students explored the function of thermocouples and resistance temperature detectors (RTD), first using a conventional digital multimeter and then using a LabView virtual instrument (VI) that had been designed for them. The original activity provided no insight into the design of the VI. Thus, the first enhancement was to have students create the VI. Later, a thermistor was added and students were required to (1) build a voltage divider circuit on a breadboard, (2) take in voltage signals through a National Instruments myDAQ device, and (3) write LabView code to transform those signals into temperature using manufacturer data. The result is a different kind of activity, from one focused on data collection and analysis to data acquisition and programming. The paper will investigate how these changes affect the pedagogical outcomes for the course.

Keywords

Thermistor, LabView, Experimentation, Data acquisition

Introduction

Hands-on activities, such as those common in laboratory courses, should be transformative experiences for students, enabling them to connect theoretical concepts with practical applications. To achieve such transformation, it is important that lab activities and assessments are designed to align with desired objectives for the course and with student outcomes for the program. As curricula and courses adapt to changes in both their students and the needs of industry, some shift in objectives is to be expected. In their seminal look at the history and evolution of laboratories in engineering education, Feisel and Rosa [1] classify objectives for laboratory activities which include “Instrumentation,” “Modeling,” and “Experiment” among 13 distinct objectives. Laboratories could be designed for any combination of these objectives in order to satisfy student outcomes for the program, i.e. ABET outcome 6: “an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.” [2] This work-in-progress looks at the progression of an activity on temperature measurement during a redesign of the laboratory curriculum. Some changes were prompted by logistical concerns, and others for pedagogical reasons. The result is a fundamentally different kind of activity for the students, from one focused on data collection and analysis to data acquisition and programming. Ultimately, this work aims to investigate how fundamental laboratory objectives were either enhanced or sacrificed as a result, and how well the activity aligns with the redesigned laboratory curriculum.

The next section presents some background on the curriculum redesign as it provides context for organic changes in a temperature measurement activity. This is followed by a description of the original activity and subsequent modifications, and the effect these have on shifting pedagogical objectives. The paper then describes research questions and outlines a plan for assessing the impact of the changes.

Background

In 2019, the Mechanical and Aerospace Engineering programs at the University of Virginia underwent a redesign of the experimental laboratory sequence. There were three overarching goals for the redesign: (1) improved alignment of the laboratory courses with the rest of the curriculum, (2) an increase in the number of hands-on experiences, and (3) improved scaffolding of experimentation skills through the sequence. The result was a move from two courses with equal lecture and lab time to three laboratory-heavy courses. The original sequence focused on experiment design, measurement, data analysis, and uncertainty estimation. The new sequence has two courses, Mechanics Laboratory and Thermal Fluids Laboratory, that align specifically with foundational courses taught in the same semester, and a third course that allows students to build upon those experiences through student-designed experiments. Concepts such as measurement, instrumentation, and uncertainty are introduced incrementally in service to syllabi driven by theoretical content in mechanics or thermofluids. Additional details on the design of the new courses are available in earlier papers [3]-[4].

Though the redesign did involve adding significant new content, many activities from the original sequence were incorporated into the new lab courses. One of these was a module on temperature measurement moved from a course in Experimental Methods to the Thermal Fluids Laboratory. The target cohort for both courses is 3rd year Mechanical and Aerospace engineering students. Thermodynamics and Fluid Mechanics are pre- and corequisites respectively. The Thermal Fluids Laboratory course consists of 1 lecture hour per week and a two-hour lab. There are typically 7 lab sections with a maximum enrollment of 21 students broken into 3 person teams. With the exception of 2020, in-person attendance has been required for the labs.

Temperature Measurement in a Sensors Lab

Prior to 2019, a temperature measurement lab was the second module in a course on Experimental Methods for junior-level Mechanical and Aerospace engineering students. The syllabus was organized around various electronic sensors, e.g. thermocouples, pressure transducers, strain gauges, accelerometers, etc. with specific experiments designed to utilize them. Prior to this, students have had limited exposure to electric circuits through their Physics II course, so these laboratory activities provided much needed practical experience with Ohm's and Kirchhoff's Laws. (Mechanical engineering students also take a course in Mechatronics but it came after Experimental Methods lab.)

At this point, the Temperature Measurement module had two objectives: (1) learn about common temperature measurement devices and (2) characterize and compare the time response for a resistance temperature device (RTD) and thermocouple. For the first part of the activity, students explored the operation of both an RTD and thermocouple by taking direct measurements from a high precision table-top digital multimeter (DMM). They were required to derive a temperature measurement using a resistance measurement of the RTD and voltage measurement of the thermocouple. For the thermocouple measurement, they were instructed in how to set up a cold-junction using an ice bath as in Fig. 1. A thermocouple operates on the principle that there is an electric potential between disparate materials (e.g. constantan and copper for a Type-T thermocouple), and that this potential changes with temperature. Thus, for any single thermocouple, there are multiple junctions: one at the sensing end where the two materials meet and one where the other ends are connected to the DMM. In the cold-junction circuit, the potentials at the DMM interface counterbalance since both sides of the connection involve the same material, i.e. copper. Thus the voltage recorded by the DMM is the difference between the sensing and reference temperatures. Connections were made using banana cables; an adaptor was provided to facilitate the connection between two thermocouples. Temperatures were derived from the Callendar-Van Dusen equation for the RTD and from tables for the type-T thermocouple. Sources of error were discussed during lecture including line and voltmeter resistance as well as uncertainty in the reference temperature.

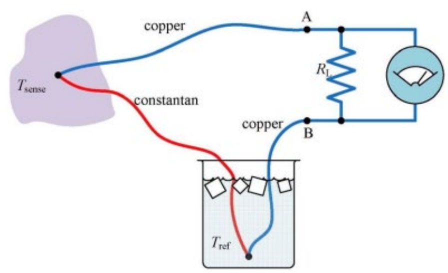

Fig. 1 Cold Junction Circuit with 2 Thermocouples, and ice bath, and DMM

In the second part of the activity, students connected the DMM and one of the thermocouples to National Instruments DAQ modules within an M-Series carrier and collected data using a LabView executable Virtual Instrument (VI) given to them. Fig. 2 shows the M-series carrier and a screen shot of the VI. The VI was used to measure the temperature vs. time of each device as it was moved from a warm bath to ice water. From this response, they were asked to determine and compare the time constants. Doing this required some experimentation with the sample rate and number of samples.

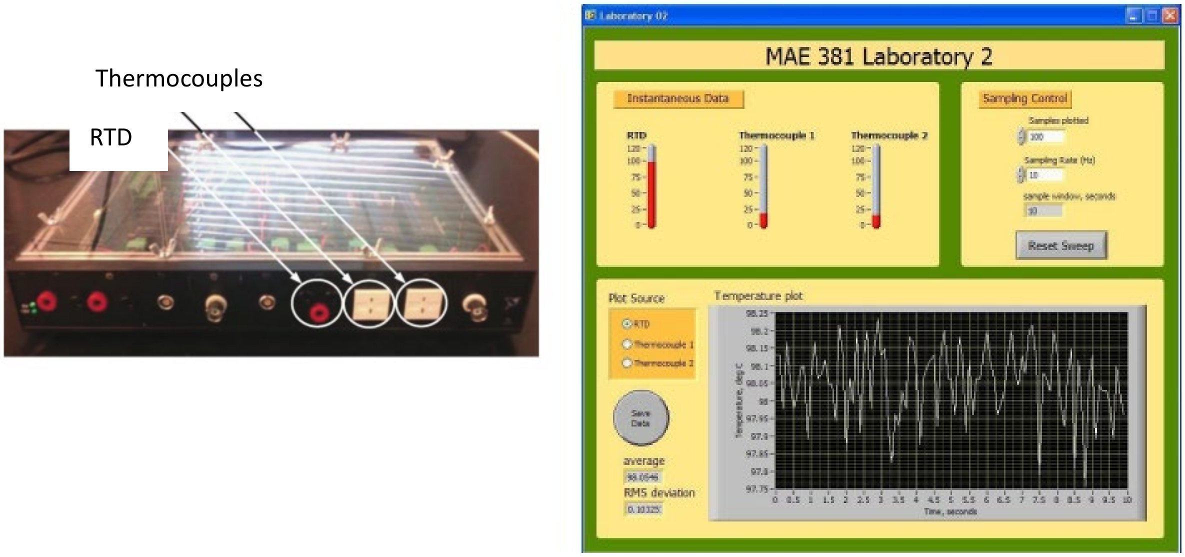

Fig. 2 (Left) National Instruments M-Series carrier showing connections for 3-prong RTD and thermocouples, and (Right) Screenshot of VI for recording temperature vs. time data.

There were many positive aspects of the activity. From working with the desktop DMM, students were able to see how both devices worked on a fundamental level. The provided VI allowed for plug and play operation so students could focus on taking measurements. However, the VI was still somewhat of a 'black box' to students. There remained a significant gap in understanding the process in going from the basic electrical measurement to the virtual instrument. For example: how is the third wire of the RTD used in the VI? or how does the VI compute a reference temperature without a cold bath?

Temperature Measurement with LabView Programming

The next iteration of the temperature measurement module attempted to address shortcomings by having students build the VI in LabView. At this point, the first part of the activity involving the desktop DMM was not changed. However, rather than use an executable VI created for them, students had to build their own VI using LabView. Since they had not been exposed to the LabView software before, illustrated instructions were provided that walked them through the process. Fig. 3 shows an example page from these instructions.

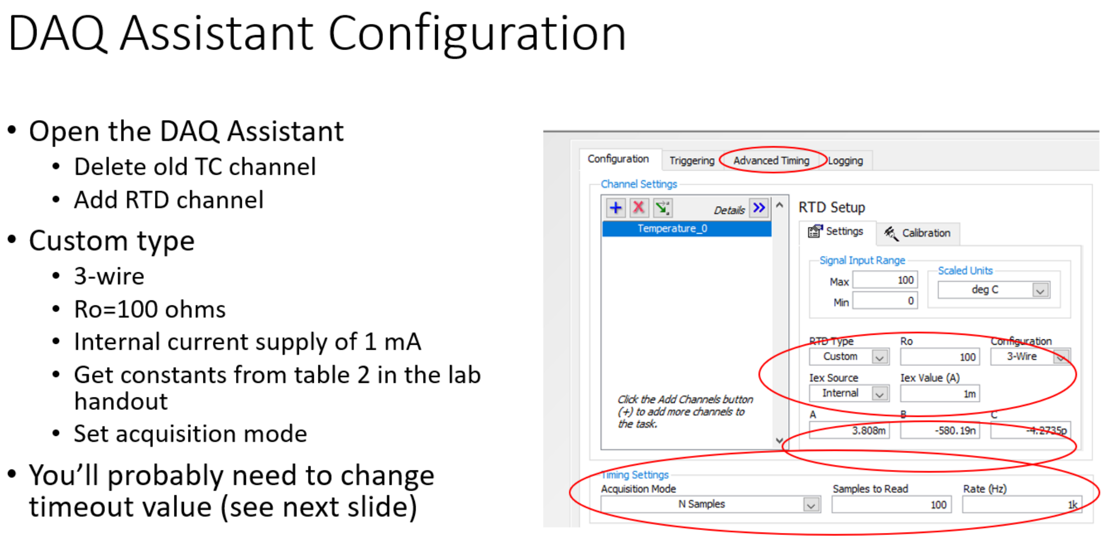

Fig. 3 Sample page from Illustrated Instructions. This shows configuration of a DAQ Assistant Block to measure temperature from an RTD. This involves checking the 0° resistance, the Callendar Van-Dusen constants, excitation voltage needed to measure resistance, the sample rate, and number of samples.

Incorporating LabView programming into the course was a bit like opening Pandora's box. There aren't any short-cuts to learning a new programming language. It takes an investment of instructional time that must come from somewhere. At the same time, it is important that there is a clear payoff for this investment. Incorporating LabView programming in a single module would not satisfy such a payoff. Students would need to continue using LabView for future activities, making it a feature that permeates the entire course. Though this would have fit in well for the Experimental Methods course, it seems less appropriate for a Thermal Fluids laboratory.

LabView Programming for a Thermistor

The latest update to the Temperature Measurement module adds a thermistor to the RTD and thermocouple. Students program a VI to read the temperature from a thermistor connected via a National Instruments myDAQ device. Unlike the thermocouple and RTD, the thermistor signal requires no amplification making it ideal to use for the low-cost, portable myDAQ. Also, as the myDAQ is not a sensor specific device, the students must first design a voltage divider circuit and then program their VI's to convert from the raw signal into temperature. A conversion relationship with constants are found from a manufacturer generated specification spreadsheet. Fig. 4 shows a sample specification report for the Vishay NTCLE100E3103GB0 thermistor.

SAP P/N : NTCLE100E3103GB0
description of the product
NTC Cu 0.6 mm leads color coded epoxy type 1e pitch in bulk

product electrical characteristics characteristics							
R25	Tref	Tol	B25/85	dB	Tmin	Tmax	Max Power
ohms	°C	%	K	%	°C	°C	mW
10000.00	25	2	3977	0.75	-40.00	125	500.00
for info:B0/100 (K	3947	for: info :B25/50(K)	3932	for info:B25/75(K)	3965	for info:B25/100(K)	3994
Steinhart & hart modified Coefficents for R/T computation					temperature scale		°C
	A	B	C	D	temperature step		0.10
T < 25 ° C	-14.63371957	4791.842	-115334	-3730535	start temperature		-40
T > or = 25 °C	-14.63371957	4791.842	-115334	-3730535	end temp		125
	A1	B1	C1	D1	$\ln\left(\frac{R}{R_{25}}\right) = A + \frac{B}{T} + \frac{C}{T^2} + \frac{D}{T^3}$		T in K
T < 25 ° C	0.003354016	0.000256985	2.62013E-06	6.38309E-08	$\frac{1}{T} = A_1 + B_1 \ln\left(\frac{R}{R_{25}}\right) + C_1\, ln^2\left(\frac{R}{R_{25}}\right) + D_1 ln^3\left(\frac{R}{R_{25}}\right)$		
T > or = 25 °C	0.003354016	0.000256985	2.62013E-06	6.38309E-08			

Fig. 4 Specification sheet for a Vishay $10k\Omega$ thermistor. The temperature conversion equation is shown in the bottom right corner.

The activity has a more robust set of educational objectives than the original temperature measurement lab. In addition to exploring the function of the 3 devices and characterizing the transient response, students also learn how to interpret thermistor specifications, and build a LabView VI that (1) collects raw data, (2) uses Math to convert to temperature, (3) determines statistics for sampled data, (4) and sends data to a file. Three weeks of lab are dedicated to the module. In the first week, students get a refresher on Ohm's Law, learn how to take measurements with the desktop DMM, and build a voltage divider circuit on a breadboard to measure an unknown resistance. In the second week, students begin to build a VI to measure temperature from a thermistor using the voltage divider circuit from week 1, the myDAQ, and LabView. Illustrated instructions are provided, but these instructions leave out the math needed to convert from raw signals to temperature. To fill in the missing steps, students need to understand their voltage dividing circuit and the thermistor specifications. They also need to have gained a basic understanding of data flow through a LabView block diagram. In the 3rd week, students explore the function of the other sensors (thermocouple and RTD) using the desktop DMM and then complete their thermistor Vis to get a temperature vs. time plot going from an ice bath to room temperature.

Plans for Assessment

The temperature measurement lab has evolved into a fundamentally different kind of activity for the students, from one focused on data collection and analysis to data acquisition and programming. Paradoxically, this shift has occurred in parallel with changes to the experimental laboratory curriculum that is organized around theoretical concepts rather than specific instrumentation. The goal for this work is to answer 3 questions:

1. Have the changes in the temperature measurement lab improved student performance with respect to the stated objectives of the activity, namely their understanding of how temperature devices work, signal conditioning, and the transient response of sensors?

2. Is the activity aligned with course objectives and program outcomes for the experimentation sequence?

3. Are skills developed in the temperature measurement lab transferrable? In other words, do students have the proficiency to use temperature sensors, data acquisition devices, and/or LabView programming for projects or tasks encountered later in the curriculum?

The first question will be answered based on student performance on specific exam questions. The second question will be difficult to assess directly. However, an exit survey for students as they complete the third and final laboratory course will be given to determine their perspectives on how certain activities including the temperature measurement lab fit into the overall curriculum. The plan for answering the third question is to take an inventory of experimentation skills demonstrated during independent experiments and design projects.

References

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