ME 103 Lab 1: Data Collection and Uncertainty

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1 Introduction / Background

The purpose of this lab is to become familiar with lab equipment, their limitations, and how to quantify them. Most modern measurements use electronic equipment, often providing a voltage from a transducer that must be converted into a useful quantity.

In this lab, we will measure voltage and current with a digital multimeter and DAQ system, process data in NI LabVIEW, evaluate measurement uncertainty, and use the results to determine the resistance of an unknown resistor with confidence interval calculations. By the end of the experiment, we will be comfortable with the data acquisition device (DAQ) and other lab equipment, basic circuitry, and uncertainty analysis.

2 Methods and Methodology

2.1 Experiment Conditions

This experiment began on Friday, September 19, 2025 at 08:15 AM with a temperature of 23.5 $^\circ C$, humidity of 43 %, and pressure of 30.21 inHg. This experiment concluded at 09:33 AM on Friday, September 19, 2025 with a temperature of 24.0 $^\circ C$, humidity of 43%, and pressure of 30.18 inHg.

2.2 Experimental Procedure

This experiment was performed in three parts. In the first part, we have a voltage divider circuit with two resistors, of which one resistance value is unknown. **The circuit diagram can be found in Appendix A.**

The circuit is connected to a 9V battery, and we use voltage measurements across the battery and the resistor of known value to determine the resistance value of the unknown resistor. These voltage measurements are done using a digital multimeter. In the second part, we perform the same measurements, this time recording voltage via a DAQ system (configured to measure analog input) and processing the data using the LabVIEW software.

In the third part, we use the same circuit and measure the current through the circuit, again using the digital multimeter. Bias and precision errors were recorded for the digital multimeter for use in uncertainty calculations; similarly, zero-offset calibration for the DAQ system was done to correct for any error present. The data and findings from these measurements, along with relevant calculations, are provided in this report.

3 Data

Section 1: DC Measurements and Uncertainty

All data in this section were obtained by the digital multimeter. The multimeter precision and bias errors were measured using shorted wires.

Initial multimeter voltage measurements:

Multimeter voltage bias error: −0.008 mV

Multimeter voltage precision error: 0.0015 mV

Average measured battery voltage: 9.3397 V

Trial	V_{R2} (Volts)
1	0.07044
2	0.07046
3	0.07045
4	0.07044
5	0.07038
6	0.07036
7	0.07048
8	0.07046
9	0.07046
10	0.07045

Table 1: Measured voltage across R_2.

Trial	V_{bat} (Volts)
1	9.3443
2	9.3336
3	9.3462
4	9.3477
5	9.3402
6	9.3327
7	9.3429
8	9.3358
9	9.3371
10	9.3364

Table 2: Measured battery voltage V_{bat}.

Theoretical measured voltage calculation (using $R_1 = 2200\,\Omega$):

$$V_{\text{out, expected}} = \frac{R_2}{R_1 + R_2} V_{\text{bat}} = \frac{15}{15 + 2200} \cdot 9.3397 = 0.06325V = \boxed{0.063 \text{ V}} \text{ (2 significant figures)}$$

Relevant calculated quantities:

Total voltage uncertainty: ±0.008 mV

Current across R_2: 4.2 mA

Power dissipated by R_2: 0.27 mW

95% confidence interval for mean battery voltage: [9.336V, 9.344V]

The full calculations for the above can be found in Appendix B, section 1.

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The **Data** section continues on the next page.

Section 2: Exploring LabVIEW

All data in this section were obtained using the LabVIEW system.

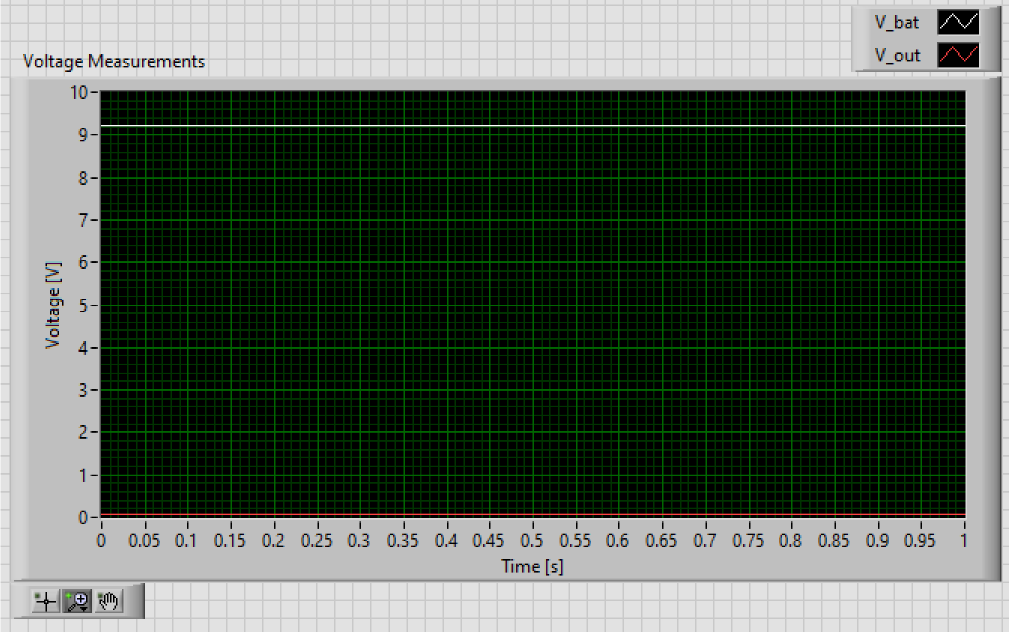

Figure 1: LabVIEW voltage measurement readings for V_{bat} and V_{out}.

Trial	V_0
1	0.000481845
2	0.000154823
3	-0.000172199
4	0.000808867
5	0.000484461
6	-0.000166966
7	0.000813258
8	0.000155778
9	0.000813258
10	0.000484518

Table 3: Zero-offset calibration: a subset of the voltage data around zero volts.

Relevant calculated quantities:

DAQ resolution: 0.00032 V

Standard deviation of calibrate ddata: 0.000233588 V

Distribution of the corrected voltage values: $\mathcal{N}(9.22054, 0.000227977)$

95% confidence interval of population mean output voltage data: $[6.47331 \times 10^{-2}\, V, 6.47423 \times 10^{-2}\, V]$

The full calculations for the above can be found in Appendix B, section 2.

Section 3: Current Measurements and Uncertainty

As in Section 1, all data in this section were obtained using the digital multimeter.

Initial multimeter voltage measurements:

Multimeter voltage bias error: 0.004 mV

Multimeter voltage precision error: 0.0015 mV

Measured battery voltage: 9.2913 V

Initial multimeter current measurements:

Multimeter current bias error: 0.00317 mA

Multimeter current precision error: 0.0015 mA

Trial	I (mA)
1	3.9438
2	3.9443
3	3.9448
4	3.9454
5	3.9458
6	3.9462
7	3.9467
8	3.9472
9	3.9477
10	3.9478

Table 4: Measured current values for the modified circuit setup (shown in Appendix A).

Trial	V_{R2} (Volts)
1	0.07044
2	0.07046
3	0.07045
4	0.07044
5	0.07038
6	0.07036
7	0.07048
8	0.07046
9	0.07046
10	0.07045

Table 5: Measured voltage across resistor R_2 (repeated from section 1).

Relevant calculated quantities:

Total voltage uncertainty: ±0.004 mV

Mean voltage measurement: 0.07044 V

Mean current measurement: 3.9460 mA

Approximate power dissipated by resistor: 0.278 mW

99.7% confidence interval for the output voltage data sample mean: [**TODO**] The full calculations for the above can be found in Appendix B, section 3.

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The **Results and Discussion** section begins on the next page.

4 Results and Discussion

In section 1 of the experiment, we measured the voltage across the battery and resistor R_2 in the voltage divider circuit shown in Appendix A. These voltage values came out to be around 9.34 V and 0.0704 V respectively. We also calculated our measurement uncertainty to be ±0.008 mV from our recorded bias and precision errors using the uncertainty propagation formula, which is orders of magnitude smaller than our data of interest.

Knowing that the 'unknown' resistor R_1 was nominally 2200Ω, we calculated the expected output voltage (i.e. voltage across R_2) to be 0.063 V, around 10% less than our measured V_{R2}. This deviation is most likely due to some deviation in R_1 from its nominal value, as we our voltage data to calculate the expected resistance of R_1 as follows:

$$V_{out} = \frac{R_2}{R_1 + R_2} V_{bat} \implies R_2 V_{bat} = (R_1 + R_2) V_{out} \implies R_{1,\text{ calculated}} = \frac{R_2(V_{bat} - V_{out})}{V_{out}} \approx 2000\Omega.$$

Since this calculated resistance value is substantially different from the nominal value, the resistance deviation is a likely contributor to the differences that we see between the expected and measured output voltage of the system. Similarly, the resistance R_2 is almost certainly not precisely 15Ω; connector components like wires and even the multimeter probes can add unwanted impedance to the circuit and affect the voltage measurements.

Using our battery voltage data, we calculated the 95% confidence interval for the battery voltage sample mean to be [9.336V, 9.344V] using the Student's t distribution with $\nu = 9$ degrees of freedom. We also calculated the power dissipated by R_2 to be 0.27 mW, will be corroborated later by a similar calculation in section 3. The full details of these calculations can be found in Appendix B, section 1.

In section 2, we repeated the same series of measurements using a DAQ system and obtained a substantial amount of data for both $V_{battery}$ and $V_{out}(= V_{R2})$. We plotted this voltage data against time in LabVIEW and obtained the following plot:

We also performed a zero-offset calibration, where we shorted the two relevant channels on the DAQ to obtain data for a state that supposedly has 0 voltage, in order to account for possible bias in the DAQ measurements. This data can be found in Table 3 and will not be reproduced here; the mean of the zero-offset calibrated data was measured to be 0.000242138V.

Using our zero-offset voltage data, we 'corrected' our measured battery and output voltages, and calculated the corrected mean of the voltage data (9.22054 V) and the corrected standard deviation (0.000233588 V). Our resulting corrected data thus follows a normal distribution $\sim \mathcal{N}(9.22054, 0.000227977)$. We verified this by plotting our data on a histogram as follows:

This histogram has an approximately Gaussian shape, with bin size set to equal the resolution of the DAQ system (which we calculated to be 0.00032 V). If the bin size had been set to less than this value, the histogram would have presented as a few discrete bins clustered around the mean as opposed to the Gaussian distribution shown, since the DAQ is unable to output values in between quantization steps. On the other hand, an overly large bin size might have obscured the quantization effect, or even the Gaussian

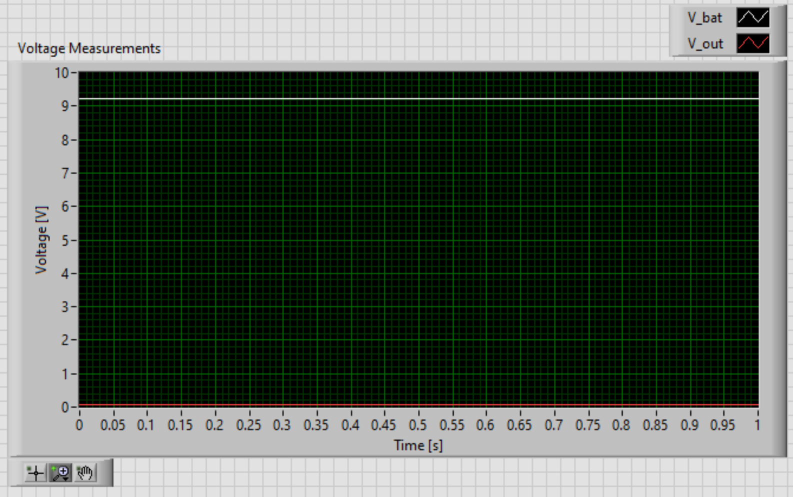

Figure 2: Uncalibrated Voltage vs. Time graph of V_{out} (white) and V_{bat} (red), in volts vs. seconds respectively.

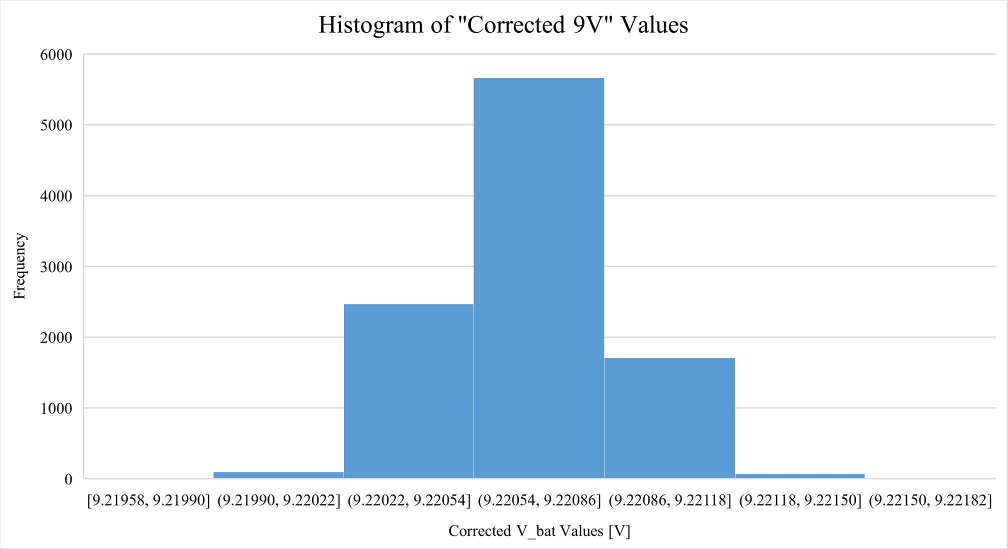

Figure 3: Histogram of "Corrected 9V" (V_{bat}) values, with bin width equal to Resolution$_{DAQ}$.

distribution altogether.

Notably, the measured voltage values from Section 2 (DAQ measurements) deviated significantly from those in Section 1 (multimeter measurements). This is summarized in the following table:

Here, we can see that the DAQ-measured values are noticeably lower than those measured by the multimeter. This is possibly due to impedance differences in the connections from the circuit to the multimeter vs. circuit to DAQ, for instance from a bad wire or probe. Another potential source of this deviation is the difference between the input impedance of the multimeter and the DAQ system themselves, which can affect the measured voltages too.

We also computed the 95% confidence interval of the population mean of the output voltage data to be $[0.0647331 \times 10^{-2}\,V, 0.0647423 \times 10^{-2}\,V]$. As before, the full details of the relevant calculations in this section can be found in Appendix B.

Measurement method	Average battery voltage (V)	Average output voltage (V)
Multimeter	9.3397	0.0704
DAQ	9.2205	0.0647

Table 6: A comparison of the battery and output voltages measured by the multimeter and DAQ.

In section 3, we re-measured the voltage across the resistor R_2, then modified our circuit to measure the current through the circuit. This was done by removing a wire to measure current in series with the circuit, which is notably different from how voltage is usually measured in parallel. The reasoning behind this change is that measuring current in parallel effectively shorts the circuit by adding a low resistance path in parallel, so the actual current passing through the multimeter is not representative of the actual circuit current in this case. The original and modified circuit diagrams can be found in Appendix A.

For our output voltage measurements in this section (using the digital multimeter), we got roughly the same data as we did in section 1 (around 0.0704 V). We also calculated a total uncertainty of ±0.004 mV, which is again several orders of magnitude smaller than our data.

We then measured a current of around 3.945 mA, which we then used (along with the voltage) to compute the resistor R_2's power dissipation to be 0.278 mW, which is very close to the 0.27 mW we calculated in section 1 of the experiment. Lastly, we computed the 99.7% confidence interval of our output voltage data to be $(9.2913, 9.3397)\ V$, accounting for possible differences in the multimeter output voltage measurements between sections 1 and 3 using our calculated uncertainty for those measurements. Since our voltage uncertainty is far smaller than our data, we are able to determine with high confidence that our average measured voltage is within a comparatively small interval.

5 Conclusion

In this lab, we learned that all physical measurements contain inherent uncertainty, which must be quantified to draw reliable conclusions. We identified different error types like bias and precision error and used them to calculate the overall uncertainty of our measurements. We also saw how instrument resolution, like the quantization in the DAQ, limits measurement fidelity. We note that proper measurement technique is essential for collecting usable data, e.g. measuring current in series to avoid short circuits. By performing statistical analysis on multiple samples, we could report results with confidence intervals rather than single, potentially misleading values. Lastly, this lab showed us that critical evaluation of data, including its uncertainties, is essential in engineering projects.

Appendix A: Circuit Diagrams

The following circuits were used in this experiment; these diagrams are originally from the lab manual and have been reproduced here. For our experiment, $R_1 = 2200\Omega$ and $R_2 = 15\Omega$ (R_1 was the originally unknown resistor whose value we want to determine in section 1).

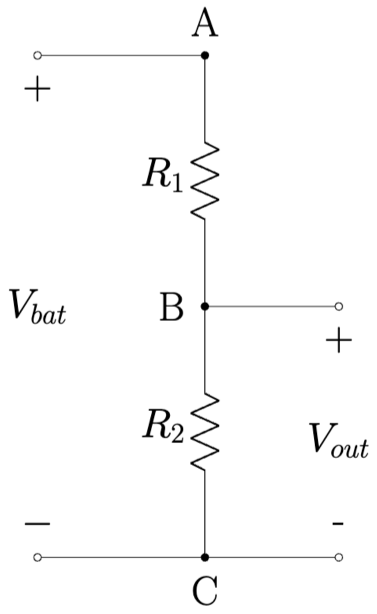

Figure 4: Original Circuit Diagram for Voltage Measurements in Sections 1 and 2.

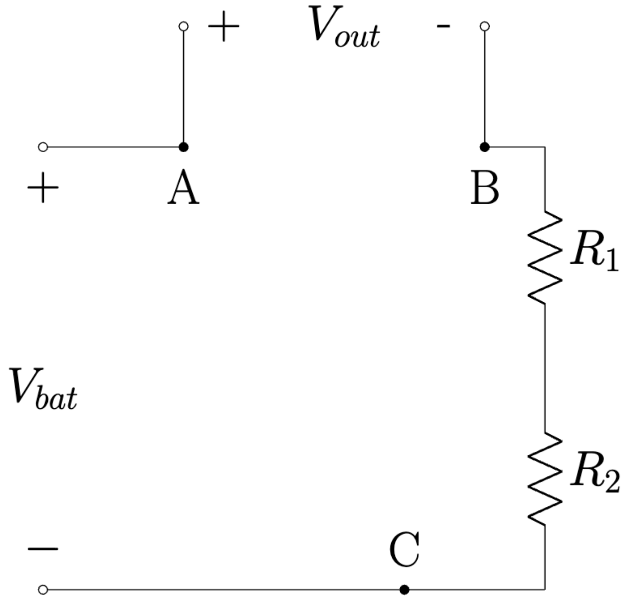

Figure 5: Modified Circuit Diagram for Current Measurements in Section 3.

Appendix B: Lab Questions

Section 1 Questions

1. With the digital multimeter, you measured the bias error and precision error at your specific range. Using this, what is the uncertainty of the voltage for your very first measurement.

   Answer. TODO

2. Predict the theoretical values for the current through the R_2 and the power dissipated by the resistor. You may or may not find the following equation helpful

$$V_{out} = \frac{R_2}{R_1 + R_2} V_{bat}, \quad V = IR$$

   Answer. TODO

   ETC.