Project Based Engineering Instrumentation With CircuitPython

A Brief Textbook Presented to the
Student Body of the University of South Alabama

Last Update: June 28, 2022

Manuscript Changes

1. Original tutorials in Google Docs created
2. Tutorials moved to LaTeX on this Github
3. December 21st, 2021 - Updated links for manuscript and hardware
4. Tutorials purchased by Tangibles that Teach and moved to url `https://tangibles-that-teach.gitbook.io/instrumentation-lab-manual/-MbMx70LQzRmEG_hS7Ld/`
5. May 30th, 2022 - Tangibles that teach went out of business and chapter began the move to Github
6. June 28th, 2022 - Work began on a Chromebook. Unfortunately the Figures folder is not back up on Git. As such a main_latest.pdf has been created that's the latest full version. The main.pdf is the version created by the Chromebook so it has new chapters but none of the older chapters. Figure files are now backup on Git but only figures from the 'Voltage Potentiometer' are currently there.

Changes Needed

1. All chapters from TTT need to be moved here
2. More theory is needed in this book or direction to further reading for the students
3. The new kit has a CPB - Might need to add a chapter explaining the difference and maybe even having the students getting the bluetooth to work.
4. The photo of the button lab could be better.
5. The circuit photo for the LSM6DS33 is not correct
6. Equations on thermistor need to be expanded
7. Equations relating voltage from protocol to Lux needs to be included
8. Example plots for light, sound, acceleration, etc needs to be expanded
9. Pendulum lab must be done in one of two ways. Either the pendulum is attached to a potentiometer or the CPX is mounted to the end of a string and data logged on board the CPX itself. The potentiometer is nice because you can record data with your laptop but the string idea is cool because you use the accelerometer. In either case you can make some really long pendulums
10. 3D printing a disc with holes on the outside to eventually mount to a shaft would be a really cool angular velocity sensor lab. Tangibles that teach could easily include a 3D printed disc that can mount to a pencil for ease of rotation. Could also include the CAD drawings so students can print more or even edit the design for better or worse performance.
11. Buying some load cells with the HMC converter and including them in the kit would add a whole lot different labs
12. Buying some magnetometers to measure magnetic field and do some sensor fusion would be neat. Could do roll, pitch and yaw calibration if we included a magnetometer.
13. Right now a lab just on roll and pitch estimation would be possible. Pendulum lab pretty much introduces them to this but could easily do an rc aircraft lab where they build an aircraft out of foam with an elevator and aileron so that the servos responds to roll and pitch change. There is a lab right now with just pitch but perhaps we could add roll to it.
14. Another cool project idea would be for the students to take temperature and light data on a cloudy day. Then have them infer if the amount of sunlight affected the temperature of the thermistor. They could plot the data with light on the x-axis and temperature on the y-axis and draw conclusions based on the plot they generate.
15. Could also have them take temperature and light data over the course of a whole day to plot sunrise and sunset and watch the ambient temperature rise and fall
16. For the aliasing lab, have the students sample as fast as possible and obtain the natural frequency of the system. Then have them sample at 1.0, 2.0 and 3.0 times the natural frequency they obtained. I originally picked 1,10 and 100 as arbitrary sampling frequencies and it would have been better to do 2,4 and 6.
17. On cool lab would be to take light data during sunset and watch light and temperature plummet.
18. Add this lab on frequency for notes

Acknowledgements

The author, Dr. Carlos Montalvo would like to acknowledge a few key members who made this textbook possible. First and foremost I would like to thank Adafruit for their entire ecosystem of electronics, tutorials, blogs and forums. Much of what I have learned here to teach Instrumentation was from Adafruit and the Adafruit Learn system and specifically people like Lady Ada and John Park who have helped shape CircuitPython and the Circuit-Playground Express to what it is today. I would also like to thank Dr. Saami Yazdani for creating the blueprint for Instrumentation at my university by creating a laboratory environment for an otherwise totally theoretical course. His course was the foundation for this textbook and for that I thank him for showing the way. I'd like to also thank and acknowledge Tangibles that Teach for giving me the opportunity to morph this loose set of projects into a textbook that can be used for multiple universities and classrooms and of course help students learn and acquire knowledge through creating.

About this textbook

This textbook has been designed with the student and faculty member in mind. First, this textbook goes hand in hand with Engineering Instrumentation taught at the undergraduate level at many universities. The course begins with simple plotting and moves into data analysis, calibration and more complex instrumentation techniques such as active filtering and aliasing. This course is designed to get students away from their pen and paper and build something that blinks and moves as well as learn to process real data that they themselves acquire. There is no theory in these projects. It is all applied using the project based learning method. Students will be tasked with downloading code, building circuitry, taking data all from the ground up. By the end of this course students will be well versed in the desktop version of Python while also the variant CircuitPython designed specifically for microelectronics from Adafruit. After this course students will be able to understand Instrumentation at the fundamental level as well as generate code that can be used in future projects and research to take and analyze data. Python is such a broad and useful language that it will be very beneficial for any undergraduate student to learn this language. To the professors using this textbook, 1 credit hour labs are often hard to work into a curriculum and "live" demonstrations in the classroom cost time and money that take away from other faculty duties. I've created this kit and textbook to be completely stand-alone. Students simply need to purchase the required materials and follow along with the lessons. These lessons can be picked apart and taught sequentially or individually on a schedule suited to the learning speed of the course. I hope whomever reads and learns from this textbook will walk away with an excitement to tinker, code and build future projects using microelectronics and programming.

Contents

1 Measuring Voltage Across a Potentiometer

1.1 Parts List

1. Laptop
2. CPX/CPB
3. USB Cable
4. Potentiometer
5. Resistor (the Ohms depends on how large your potentiometer is)

1.2 Learning Objectives

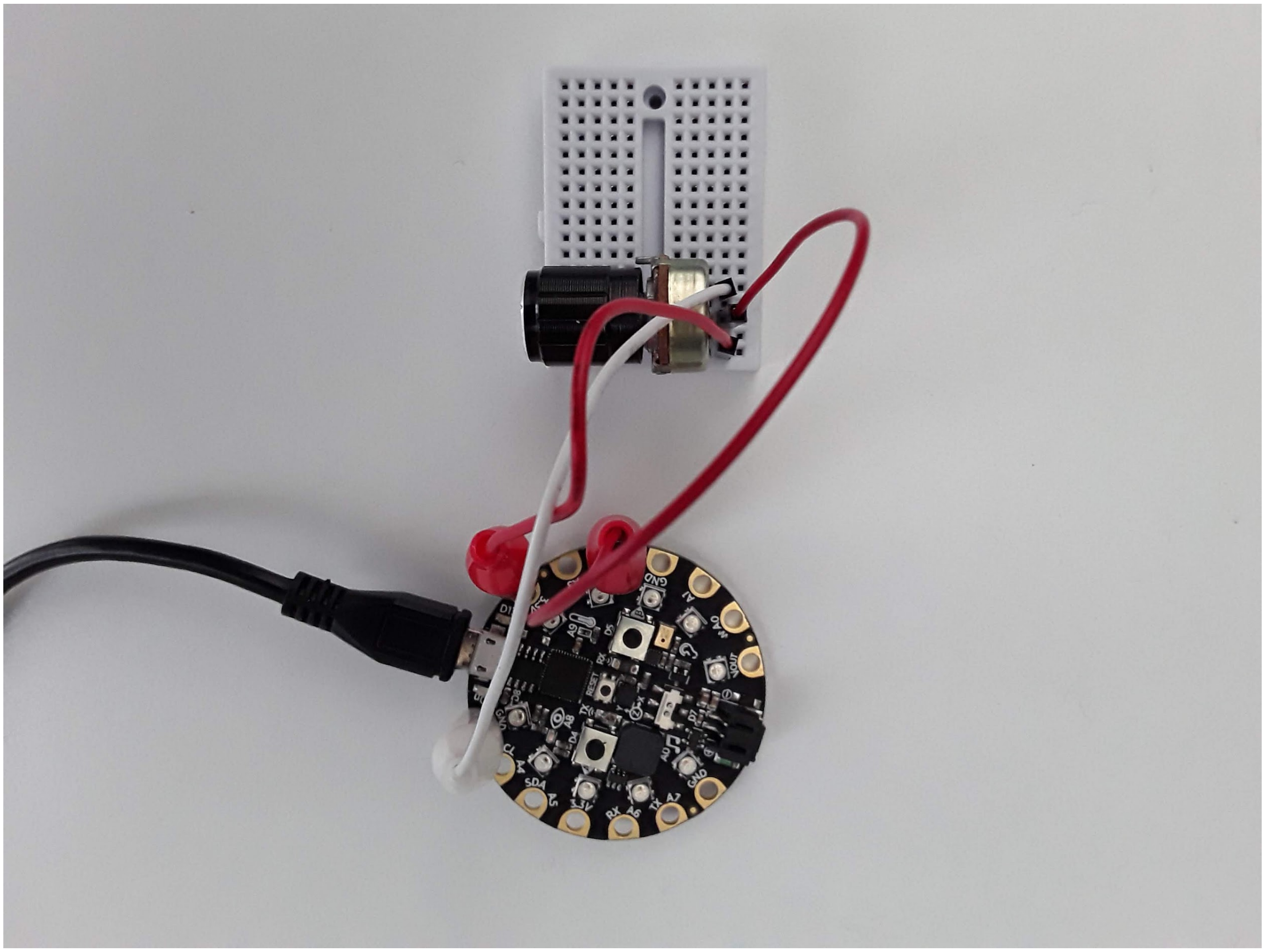
1. Understand voltage division of resistors in series
2. Measure an analog signal on the CircuitPlayground
3. Understand the binary measurement done by the analog to digital conversion (ADC)

1.3 Getting Started

At this point you've learned about analog to digital converters (ADC). It turns out that the CPX has 8 analog ports hooked up to a 3.3V logic 16 bit ADC. The input range on the ADC is 0 to 3.3V and the output range is 0 to 65536 which is 2^{16} hence 16 bits. In order to get accustomed to the ADC on the CPX, we're going to do a simple example where we measure the voltage drop across a potentiometer. You can read about potentiometers online if you wish. Basically though, a potentiometer is a variable resistance resistor that changes resistance by turning a knob. The knob changes the connection point of a wire and thus the length of the wire. This in turn changes the resistance. Potentiometers come in all shapes and sizes. Here are some examples.

Here's my circuit all hooked up. Two legs are connected to 3.3V and GND while the middle leg of the potentiometer is connected to pin A2.

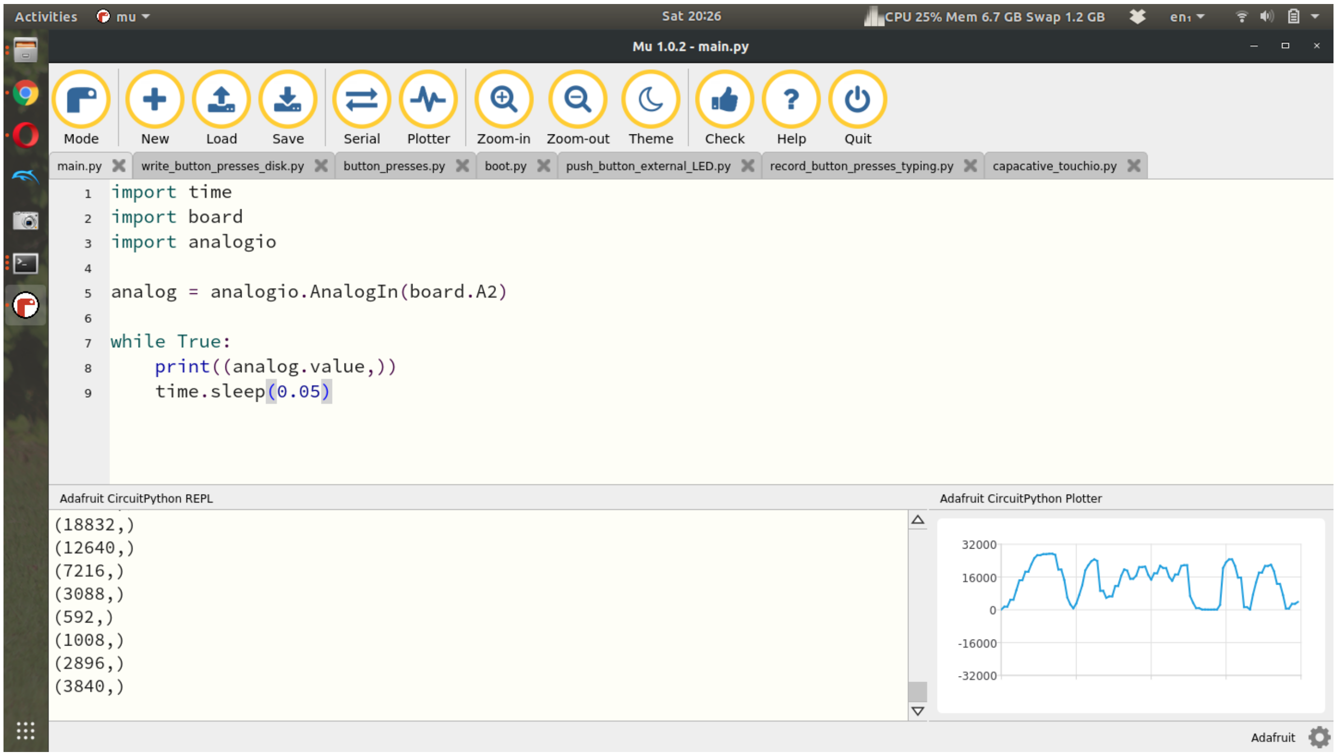
CAUTION!!!: Some potentiometers do not have enough resistance when turned all the way down. I suggest that you put a resistor in between the third leg and ground. Some experimenters have melted plastic or gotten really hot. One student even blew up a potentiometer.



There is a relevant Adafruit Learn Tutorial to help with the *analogio* module but I'll explain the minimum required here to get some analog values plotted in *Plotter* and Python on your computer. First let's take a look at some simple example code to read an analog signal and plot it using the *Plotter*.

```
1  import time
2  import board
3  import analogio
4
5  analog = analogio.AnalogIn(board.A2)
6
7  while True:
8      print((analog.value,))
9      time.sleep(0.05)
```

In the example code above, lines 1-3 again import the necessary modules with *analogio* being the new module here. Line 5 creates the analog object by attaching pin A2 to the analog function. Lines 7-9 then simple read the analog value and print it to *Serial* and the *Plotter*. Running this code on my laptop and turning the knob on the potentiometer produces this output. My potentiometer has a very large knob on the front and is easy to turn. Some potentiometers have a small screw on top that you need to turn with a screwdriver. Turning the screw or the knob results in chaning the resistance and therefore changing the voltage read by the CPX.



For this lab I want you to spin the potentiometer all the way to one side and then the other while recording time and the analog value. I then want you to plot the data with time on the x-axis and voltage on the y-axis. Remember to convert a digital output to voltage you just need to use the equation below where D is the raw value from the analog port. 3.3V is the range of the ADC and 2^{16} is the maximum value the ADC can represent.

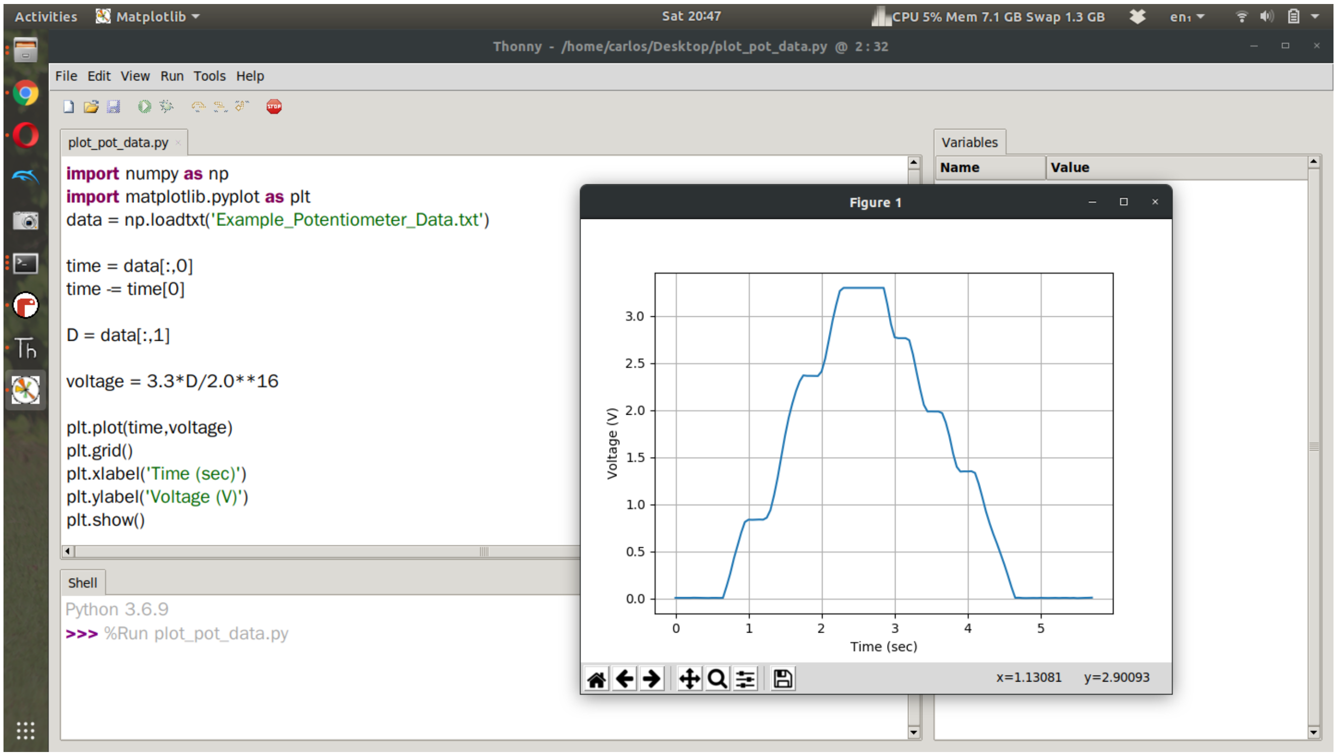
$$V = \frac{3.3D}{2^{16}} \tag{1}$$

After doing this experiment myself, this is the plot I obtain. The code is not provided as reading data and plotting has been discussed in a previous lab (See chapter **??**). From the screenshot though you can see how I convert the digital output to an analog signal.

NOTE THAT ON LINE 6 IT READS

```
time -= time[0]
```

Notice the minus sign in front of the equal sign. That effects a lot.



Your assignment for this lab is to do the same as I've done above. Wire up the potentiometer, read the analog signal and plot it in Python on your desktop computer. I've made some youtube videos on first just creating the circuit and plotting the data and then another video where I write data to the CPX using method 3.

1.4 Assignment

Upload a PDF with all of the photos and text below included. My recommendation is for you to create a Word document and insert all the photos and text into the document. Then export the Word document to a PDF. For videos I suggest uploading the videos to Google Drive, turn on link sharing and include a link in your PDF.

1. Use method 1, 2 or 3 and save time and button presses to a text file
2. Include a video explaining which method you are using to record button presses and show yourself pressing the CPX button a few times and recording data. Make sure to wave and introduce yourself - 30%
3. Copy and Paste your CPX code used to log data - 20%
4. Copy and paste your Python desktop code used to plot your data - 20%
5. Include a plot of your button presses with time on the x-axis and button presses on the y-axis (no screenshots) - 30%