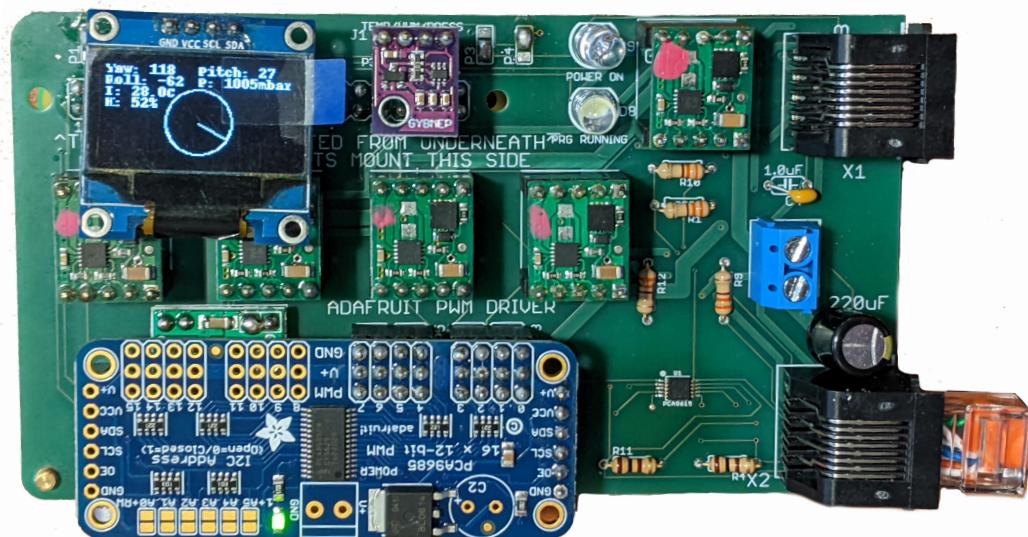


Raspberry Pi Single-Board-Computer Control of a USB Gamepad for Use With SeaPerch

Undersea Technology Apprentice Program
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Abstract

This document describes the use of the Raspberry Pi Rev. 4 single-board-computer (SBC) to interface with a Universal Serial Bus (USB) gamepad for directional and variable speed control of the underwater vehicle SeaPerch. This forms the basis of the Undersea Technology Apprentice Program (UTAP), held at the Naval Undersea Warfare Center, Division Newport, RI. The hardware and software components as well as the basic circuit requirements will be discussed. Due to the complexity of the circuit, a printed circuit board (PCB) will be provided, to which the student will add all the necessary electrical components. A basic working Python (a software language) program will be provided that will enable the Raspberry Pi to interface with the USB gamepad, establishing variable speed thruster control to the SeaPerch. Teams of students will modify the baseline SeaPerch mechanical and propulsion design to complete a series of challenges simulating real-life mission scenarios. The students will modify the stock Python code to accommodate the new vehicle configuration and propulsion layout. Fully completed hardware and software designs will compete against other designs to determine the best design and execution.

****NOTE: This document assumes you have already built a standard SeaPerch kit!****

1 Introduction

The Raspberry Pi (RPi) model 4 is a Broadcom BCM2711, Quad core Cortex-A72 (ARM v8) 64-bit System on a Chip (SoC) running at 1.5GHz single board computer capable of hosting a number of Linux distributions (operating systems). This means, for all intents and purposes, the Raspberry Pi is computer in the modern sense of the word. It can establish communications on the Internet for web access, it runs stand-alone applications like LibreOffice (an Open Source alternative to Microsoft Office products), Mathematica (a software equations solver), as well as a host of games (yes, even Minecraft.) The board itself doesn't appear to be much of anything resembling a computer - just a collection of integrated circuits and USB ports, with an Ethernet jack and HDMI (High Definition Multimedia Interface) ports. But don't let appearances fool you, this board can do virtually anything your Smartphone can do (with the right add-ons), and quite a few things that your Smartphone can't.

We will be using an extremely tiny portion of the Raspberry Pi's capabilities for this project. However, what it provides in the process is a fantastic platform to learn about rapid prototyping, computer communications, Linux (Unix computing), Python programming language, and the Internet of Things (IoT).

At the completion of the build, the control module will be used to control a modified version of the underwater vehicle SeaPerch [2]. Each team will compete against each other in timed trials to complete



Figure 1: Raspberry Pi, rev. 4.

a series of mission scenarios. The team with the best score will win that portion of the competition. However, you will also be judged on your ability to keep an engineering notebook and write a final comprehensive report. The team with the overall highest score from all three phases will win the competition.

2 The Raspberry Pi

The RPi is a computer - connect it to a monitor and add a mouse and keyboard and it will be indistinguishable from any other computer you have ever used. It has a desktop and folders, drop down menus, and indicators to tell you it's connected to wireless protocols (Wi-Fi, Bluetooth). To reduce the number of peripherals (monitors, keyboards, mice, etc.) needed to host multiple RPis during this apprenticeship, each RPi has been assigned a static IP (Internet Protocol) address so you can communicate with it using your group's assigned laptop. (You can even communicate with it using your Smartphone, but let's hold off on that for now.) We will be using what is known as a Secure Shell (SSH) interface, which is a protocol that one computer uses to talk to another computer. Google's Chrome Browser has an extension (integrated application) cryptically called Secure Shell Beta which we will use to interface with the RPi.

Using the shell, you have only a command line to navigate all the files and folders on your RPi. It will likely take a little time for you to become comfortable navigating a computer using nothing more than a keyboard, but eventually, you'll be surprised how efficient it really is. Remember, this is how ALL computing was done in the pre-windows (both small 'w' and big 'W') days. However, the RPi does have a desktop GUI and for the savvy student, a window can be created that will host the RPi's graphic desktop on a remotely connected computer (i.e. Virtual Desktop).

The Raspberry Pi Foundation, the "company" responsible for the RPi, started producing these single-board computers in 2012. They initially thought they'd be lucky to sell 50 thousand. Ten short years later, they have sold over 38 Million RPis. Check out <https://www.raspberrypi.org> for more information.

2.1 Connecting to the Pi

As mentioned, each RPi has been assigned its own individual IP address. This implies that your RPi has already been provided a microSD card with a pre-loaded operating system - which it has. Until recently, the preferred OS distribution for RPi was Raspbian Buster (Raspbian is a portmanteau of Raspberry and Debian, a popular Linux distribution. The "flavor" Buster is named after Buster from Toy Story . Prior to the Buster distro (short for distribution), there was Stretch, and before that there was Jessie, and before that there was Wheezy, and before that was Squeeze, and before that was Lenny, and before that was Etch ... you get the point.) The entire operating system is stored on a microSD card. If you remove the microSD card, the RPi will stop functioning and it will need to be rebooted with the card reinserted.

To coincide with the release of the newest Raspberry Pi hardware (Raspberry Pi 4), the operating system is now simply referred to as Raspberry Pi OS. The Toy Story lineage is dead - long live the Toy Story lineage!!

Like all modern computers, the RPi has a Graphical User Interface (GUI) desktop, just like the one you're using now. However, because the RPi runs a Linux operating system, it can be run perfectly well from the command line. What is a command line, you ask? Before the mouse and GUI environments (aka window (small 'w') environments) there was the command line - a directory based access point to the files and programs on a computer. Windows (big 'W') has a command line interface, accessible from the "Search" window as "cmd" (figure 2). In Linux, the command line isn't just a feature, it's a way of life¹. Because your RPis have been supplied with an operating system (it's on the removable microSD card), and because each RPi has it's own unique IP address, you can connect to and control it using the previously mentioned SSH. Insert the microSD card in the slot under the RPi (figure 3).

¹Without going into much detail, Linux as an operating system, is a clone of the Unix operating system, developed in the 1970s at the former AT&T Bell Labs. Linux was originally crafted by software engineer Linus Torvalds - the resulting name Linux is a mash of Linus and Unix.

Make sure your RPi has power by inserting the USB C side of the cable into the RPi and the other end into your laptop - just like charging your phone.

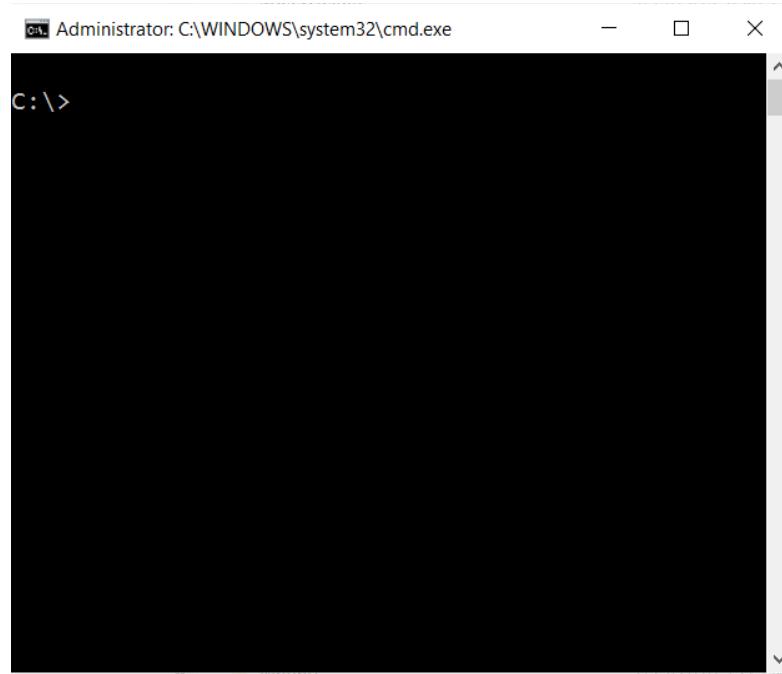


Figure 2: A command window in Windows

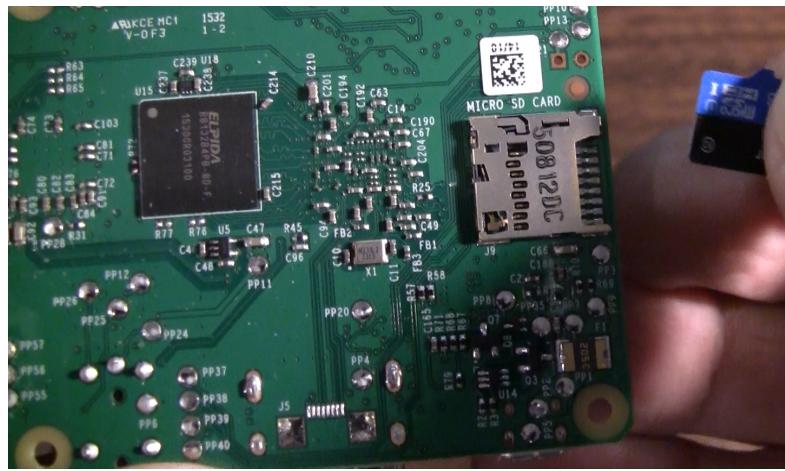


Figure 3: Insert the microSD into the RPi (from https://arachnoid.com/raspberry_pi/)

On your laptop, open the Google Chrome browser, click the APPS icon (figure 4, left) and launch the Secure Shell application (figure 4, right). If all goes well, it should look like figure 5. Where you see

the left red arrow, you will enter `pi@192.168.1.XXX`, where XXX will be your particular address. For instance, figure 5 shows `pi@192.168.1.151`. For the right red arrow (port), enter the number 22. Port 22 is the standard SSH TCP (Transmission Control Port) port. Other well known ports are 80 (http), 443 (https) and 5900 (Virtual Network Connection), to name but a few.

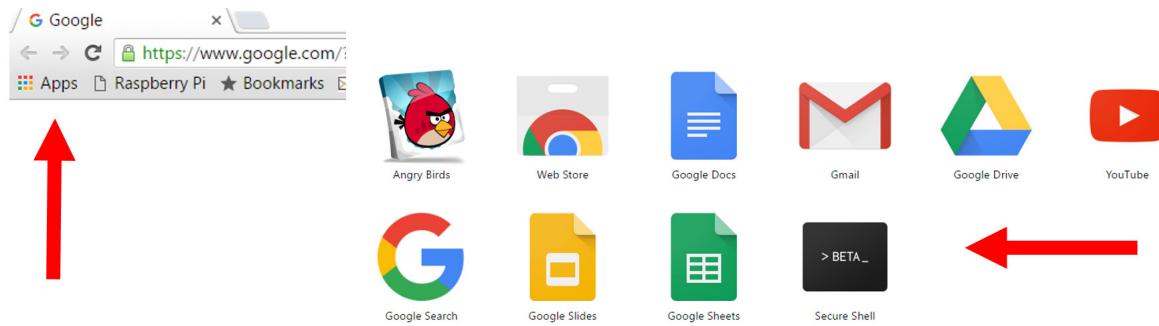


Figure 4: Access the "Apps" link

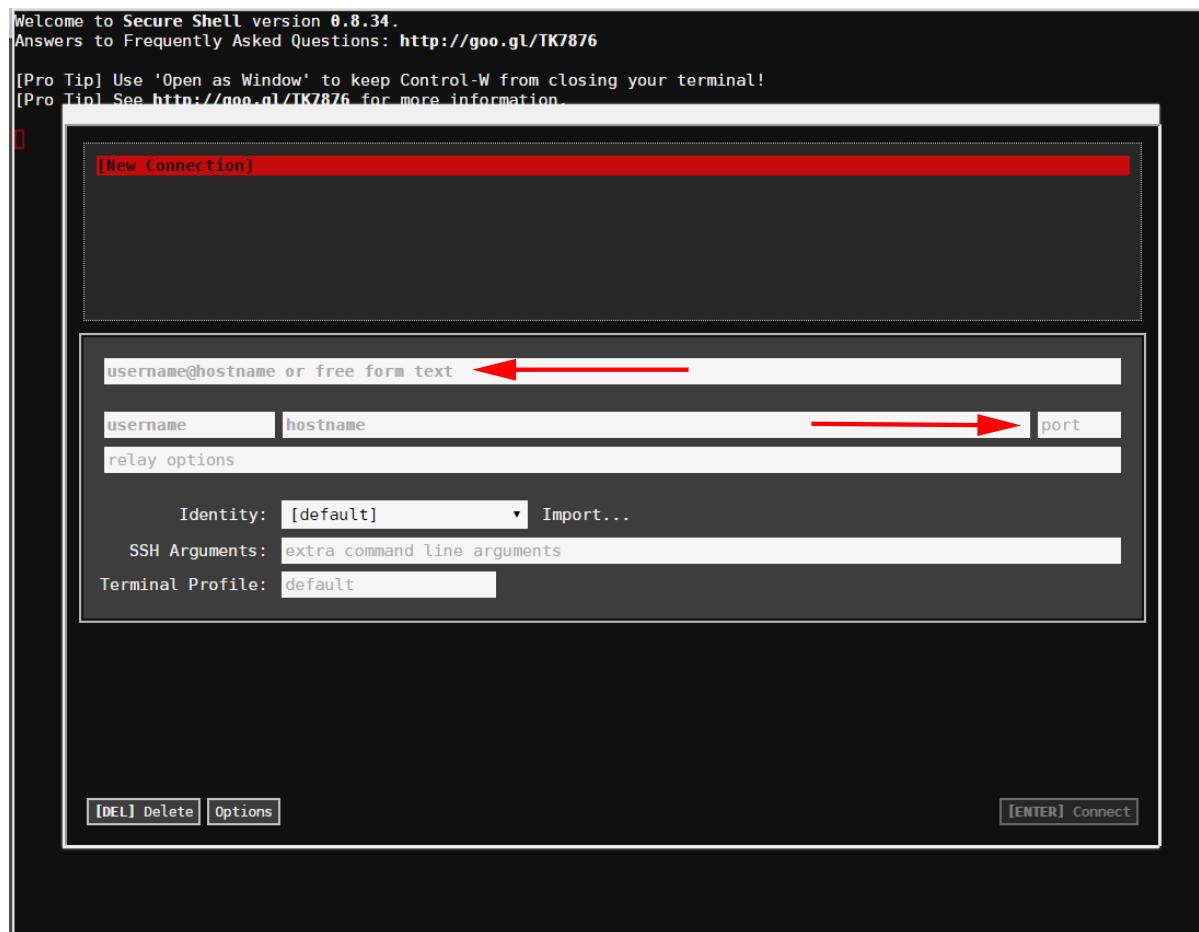


Figure 5: This screen will launch when you select the Secure Shell App.

The example in figure 6 has been populated with the address pi@192.168.1.151. YOURS WILL BE DIFFERENT! When the address and port have been entered, simply hit ENTER at the bottom of the screen and you should see the screen in figure 7. Allow the connection by typing out yes. You'll be prompted for the password, which we changed from the default raspberry to blueberry - case sensitive. The connection will be authenticated and you will see the screen depicted in figure 8.

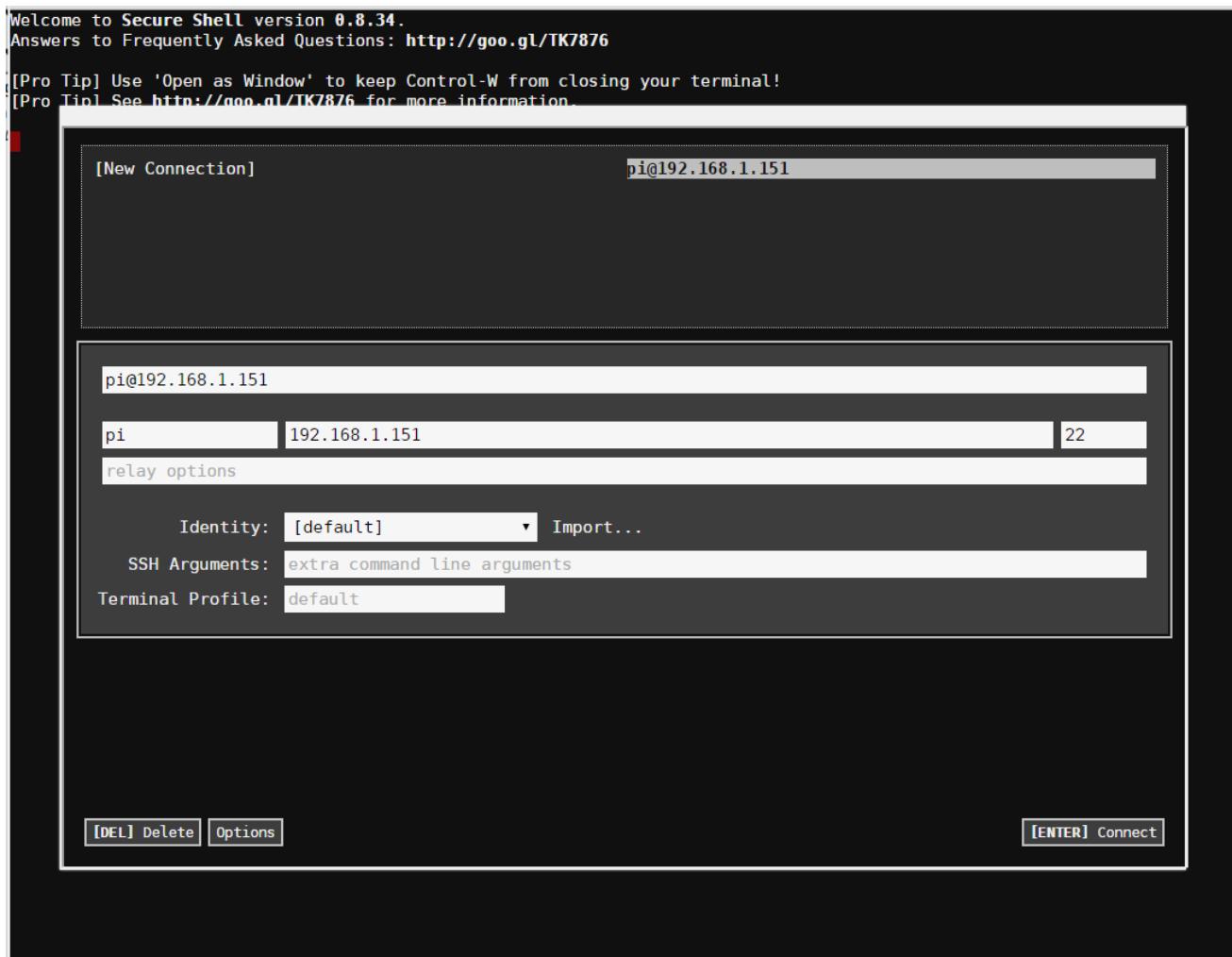


Figure 6: Populated SSH screen. YOURS WILL BE DIFFERENT!

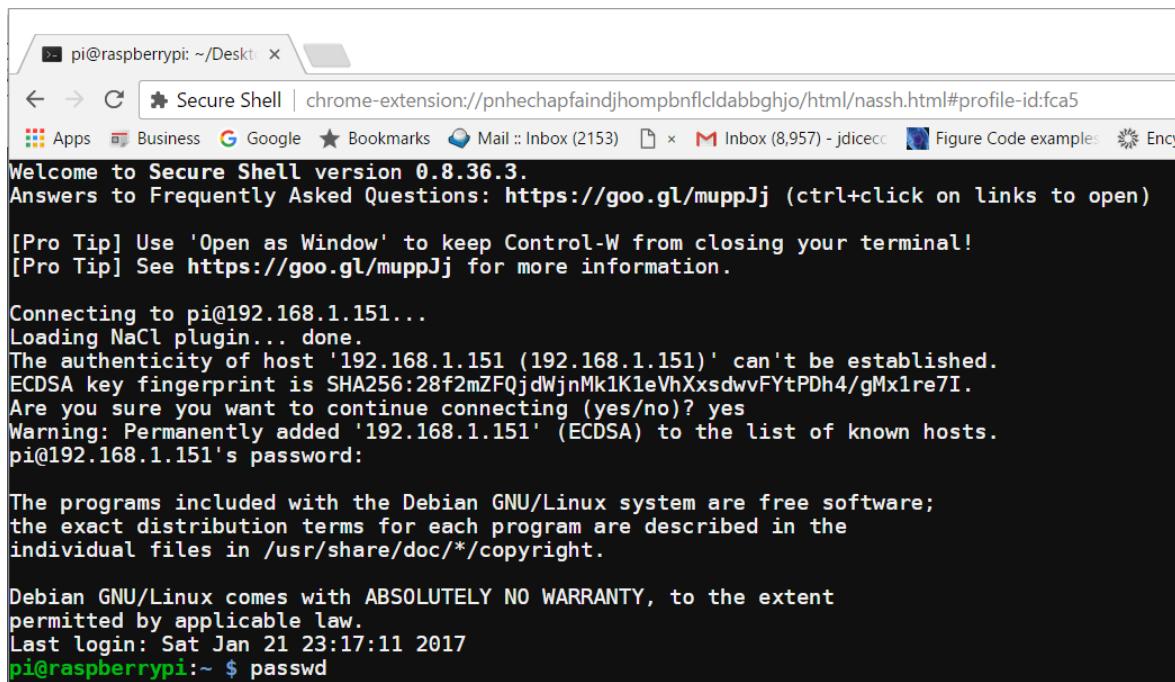
A word of warning, i.e. pay attention to this! The default username for all Raspberry Pis is pi and the default password is raspberry. We are using the local area network (LAN) in the Undersea Collaboration and Technical Outreach Center (UCTOC) to "remotely" (wirelessly) connect to the RPis from a laptop. All one needs to remotely control any of the RPis being used in the UCTOC is the username, password, and IP address. There are 256 possible IP addresses on the .XXX subnetwork and 2 of them are 192.168.1.0 (the gateway to the outside world) and 192.168.1.1

```
Welcome to Secure Shell version 0.8.34.
Answers to Frequently Asked Questions: http://goo.gl/TK7876

[Pro Tip] Use 'Open as Window' to keep Control-W from closing your terminal!
[Pro Tip] See http://goo.gl/TK7876 for more information.

Connecting to pi@192.168.1.151...
Loading NaCl plugin... done.
The authenticity of host '192.168.1.151 (192.168.1.151)' can't be established.
ECDSA key fingerprint is 88:9f:32:d1:db:5b:4c:b8:81:54:90:0d:b1:a9:08:55.
Are you sure you want to continue connecting (yes/no)? █
```

Figure 7: This screen will display if you have entered the information for your RPi correctly - do not be alarmed.



The screenshot shows a web browser window with a tab titled "Secure Shell" and the URL "chrome-extension://pnhechapfaindjhompbnflcdabbghjo/html/nassh.html#profile-id:fca5". The browser interface includes a toolbar with "Apps", "Business", "Google", "Bookmarks", "Mail :: Inbox (2153)", "Inbox (8,957) - jdicecc", "Figure Code examples", and "Ency". Below the toolbar, the browser displays the same SSH connection information as Figure 7, including the welcome message, security warning, and the "Are you sure you want to continue connecting (yes/no)? yes" prompt. The bottom of the browser window shows the standard Debian Linux copyright notice and the command prompt "pi@raspberrypi:~ \$ passwd".

```
Welcome to Secure Shell version 0.8.36.3.
Answers to Frequently Asked Questions: https://goo.gl/muppJj (ctrl+click on links to open)

[Pro Tip] Use 'Open as Window' to keep Control-W from closing your terminal!
[Pro Tip] See https://goo.gl/muppJj for more information.

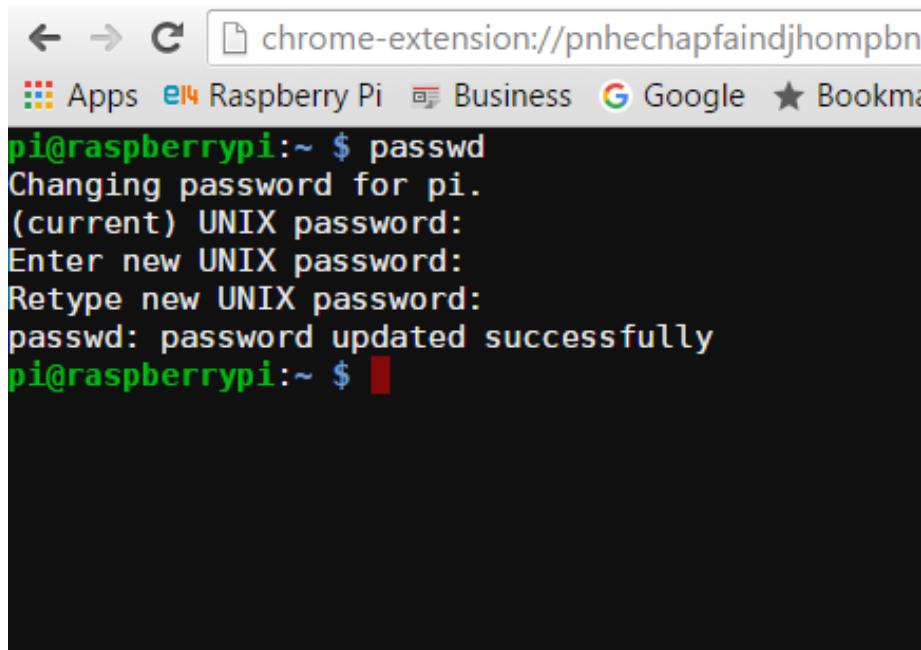
Connecting to pi@192.168.1.151...
Loading NaCl plugin... done.
The authenticity of host '192.168.1.151 (192.168.1.151)' can't be established.
ECDSA key fingerprint is SHA256:28f2mZFQjdWjnMk1K1eVhXsdwvFYtPDh4/gMx1re7I.
Are you sure you want to continue connecting (yes/no)? yes
Warning: Permanently added '192.168.1.151' (ECDSA) to the list of known hosts.
pi@192.168.1.151's password:

The programs included with the Debian GNU/Linux system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Sat Jan 21 23:17:11 2017
pi@raspberrypi:~ $ passwd
```

Figure 8: Success! You have just connected your computer to the RPi over the internet!

(the address of the router providing the other 254 addresses). The remaining 254 are a combination of dynamic addresses (the router chooses) and static (the user/machine chooses). There are a number of IP address sniffing tools that can quickly locate what is connected to a LAN. The point is, it may be a good idea to change your password. This can easily be accomplished once you log in to RPi. Simply type `passwd` and enter your current password. It will then prompt you for a new password and a repeat of your new password (figure 9). This way, no other teams (or mentors) can sabotage your work ... or at least it will be a lot harder for them to sabotage your work.

A screenshot of a terminal window titled "chrome-extension://pnhechapfaindjhombn". The window shows a command-line interface for a Raspberry Pi. The user has run the command `passwd`. The terminal displays the following text:

```
pi@raspberrypi:~ $ passwd
Changing password for pi.
(current) UNIX password:
Enter new UNIX password:
Retype new UNIX password:
passwd: password updated successfully
pi@raspberrypi:~ $
```

The terminal window has a dark background with white text. The title bar and some menu items are visible at the top.

Figure 9: Changing the password on the RPi.

The UTAP course is 3 weeks of very intensive engineering experience. It was designed to give you a realistic glimpse into one small aspect of the type of work engineers do everyday. Hopefully, you'll leave this apprenticeship with a better understanding of the ingenuity it takes to be an engineer (yes, both words have the same root, from the Latin *ingeniare* - to devise). The Raspberry Pi was chosen for this internship due to its ease of use, powerful computing capabilities and vast user support as well as relatively low cost. There are many online resources for projects that can be run on the Raspberry Pi, the primary being the Raspberry Pi Foundation website provided earlier (<https://www.raspberrypi.org/>). Here you can find downloads for the many different operating systems that can currently run on the RPi as well as links to many affiliates and an extensive network of forums and collaboration groups.

3 Preloaded Software

As mentioned, the RPis that have been assigned to the teams have already been loaded with a copy of Raspian Jessie, a Linux distribution based on Debian, which is itself a Linux distribution, based on the Linux kernel, or operating system. While that may sound a bit convoluted, consider this - Windows 95, Windows 98, Windows ME, Windows NT, Windows 2000, Windows XP, Windows Vista, Windows 7, Windows 8, Windows 8.1, Windows 10, Windows 11 ... Windows 392547 one day maybe.

In addition to the operating system, other software and libraries were installed to speed the development of the software we will use to control the Remotely Operated Vehicle (ROV). **YOU DO NOT HAVE TO DOWNLOAD ANY SOFTWARE - IT HAS ALREADY BEEN DOWNLOADED AND INSTALLED ON YOUR RASPBERRY PI.** The following steps **WERE** taken:

- Download and install Raspberry Pi OS
- sudo apt-get update && sudo apt-get upgrade (updates the distribution and other packages installed on the Pi)
- Modify Internet/Router communication files to setup network for static IP
 - /etc/network/interfaces
 - /etc/wpa_supplicant/wpa_supplicant.conf
 - /etc/dhcpcd.conf
- sudo apt-get install joystick
- sudo apt-get install python-dev python-rpi.gpio (python-rpi.gpio is part of the OS distribution)
- sudo apt-get install python-smbus (System Management Bus needed to communicate over I2C, also included with the OS download)
- uncomment /boot/config.txt dtparams (for hardware i2c/spi configuration)
- sudo pip3 install --upgrade adafruit-python-shell
wget <https://raw.githubusercontent.com/adafruit/Raspberry-Pi-Installer-Scripts/master/adafruit-circuitpython-all-in-one-repository/adafruit-circuitpython-all-in-one-repository.py> (the baseline libraries from Adafruit that all the other sensor software is based upon)
- pip3 install adafruit-circuitpython-pca9685 (this installs the Adafruit Python code we need for the PWM driver)
- sudo pip3 install adafruit-circuitpython-servokit (this installs the OTHER Adafruit Python code we need for the PWM driver)
- pip3 install adafruit-circuitpython-ssd1306 (this installs the Adafruit Python code we need for the OLED screen)
- sudo pip3 install adafruit-circuitpython-bme280 (this installs the Adafruit Python code we need for the temperature, humidity and pressure sensor)
- sudo pip3 install adafruit-circuitpython-fxos8700

`sudo pip3 install adafruit-circuitpython-fxas21002c` (This installs the software to use the NXP 9 Degree of Freedom (DoF) inertial navigation system (INS ... also known as IMU - inertial measurement unit)

4 The "Sensors"

We will be using two sensors with our UTAP project - a BME280 Temperature, Humidity, and Pressure (THP) sensor, and the NXP 9 DoF IMU, from which we'll use the FXOS8700 magnetometer and the FXAS21002C gyroscope (Fig. 10). Each of these sensors communicates with the Raspberry Pi using a serial communication protocol called I2C (or I^2C , or IIC, for Inter-Integrated Circuit). We'll be discussing I2C in the lecture portion of the program. For now, it's enough to know that it's just a way for one integrated circuit to talk to another integrated circuit.

The other two "sensors" aren't really sensors at all but function as peripheral devices to the Raspberry Pi. One is an Organic LED (OLED) screen for heads-up display and the other is a Pulse Width Modulation (PWM) Board that extends the Raspberry Pi's ability to produce multiple PWM signals. (There is a section later (Sec. 6) in the document that explains exactly what this means for motor control.)

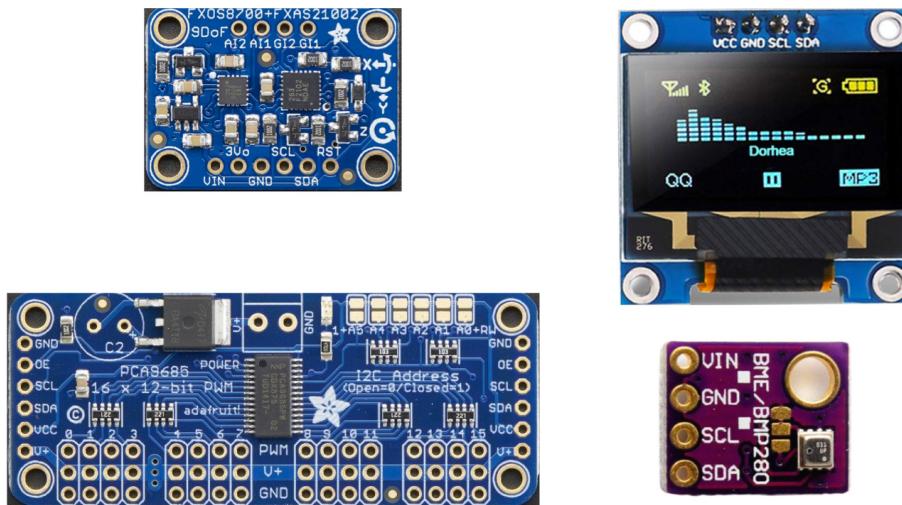


Figure 10: Clockwise from upper left, the IMU, the OLED screen, the BME280, and the PWM board (not really a sensor, but does use the same communication protocol (I2C) as the sensors.).

A quick blurb about the IMU. Since this sensor will be mounted to your ROV to give you attitude (yes, there is another definition of attitude) information, it is positioned a very long distance away from the RPi which reads the data. Communications over this length of cable (over 35 feet) is challenging

as the signal loses integrity - think about the static as you get further away from your favorite radio station (wait, do people still listen to the radio?). This is overcome by using a protocol that provides a differential pair of wires for the data and a differential pair of wires for the synchronizing clock. The noise on these pair of wires will be identical which means taking the differential will yield only the underlying signal. This is the way these long distances are achieved in aircraft, trains and automobiles as the sensor information must be relatively noise free in order to get an accurate value. In order to establish this differential I2C, a special chip (PCA9615) is installed on your topside PCB as well as a tiny PCB inside the housing that holds the IMU. The I2C communications are split into a differential pair at the topside PCB and recombined at the sensor PCB - we'll talk more about this during the I2C lecture when we see a demonstration of what happens when you try to communicate over I2C WITHOUT this type of technique.

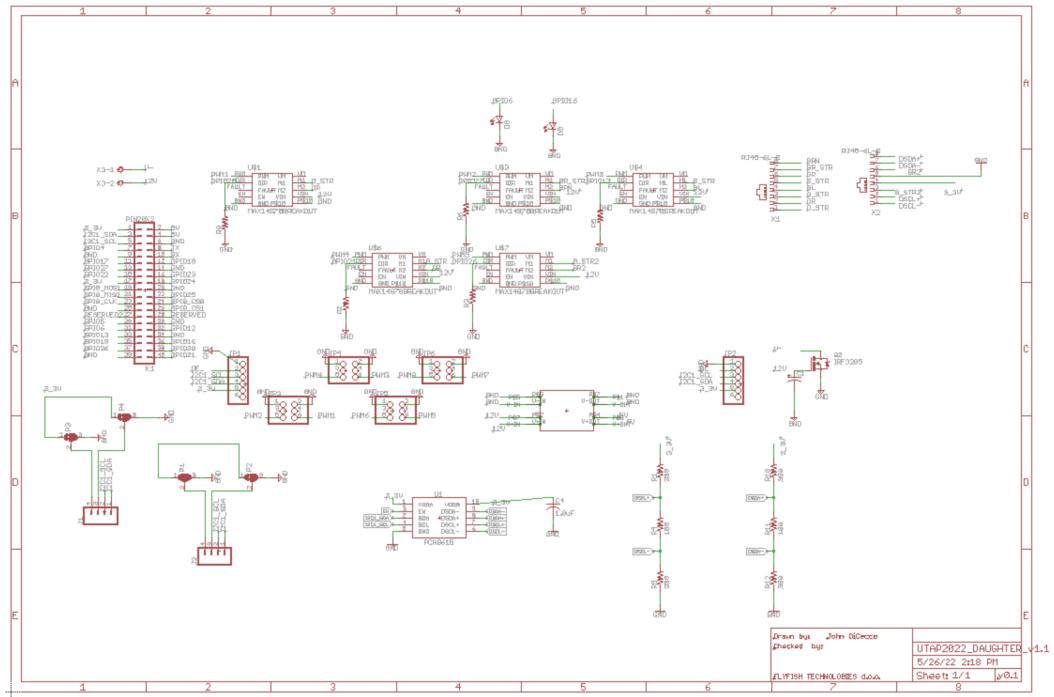
5 The Circuit

The goal of this project is to control UP TO 5 individual motors on an ROV with a USB gamepad controller (you may find you need less than 5). There is no ready-made circuit or software that will accommodate this task while simultaneously maintaining the SeaPerch standard output from an RJ45 Ethernet jack. Therefore, we needed to design and build our own printed circuit board (figures 11(a) and 11(b)) as well as develop our own software. And remember that little blurb about the IMU? We had to design a separate board to handle the differential signals (Figures 12(a) and 12(b)).

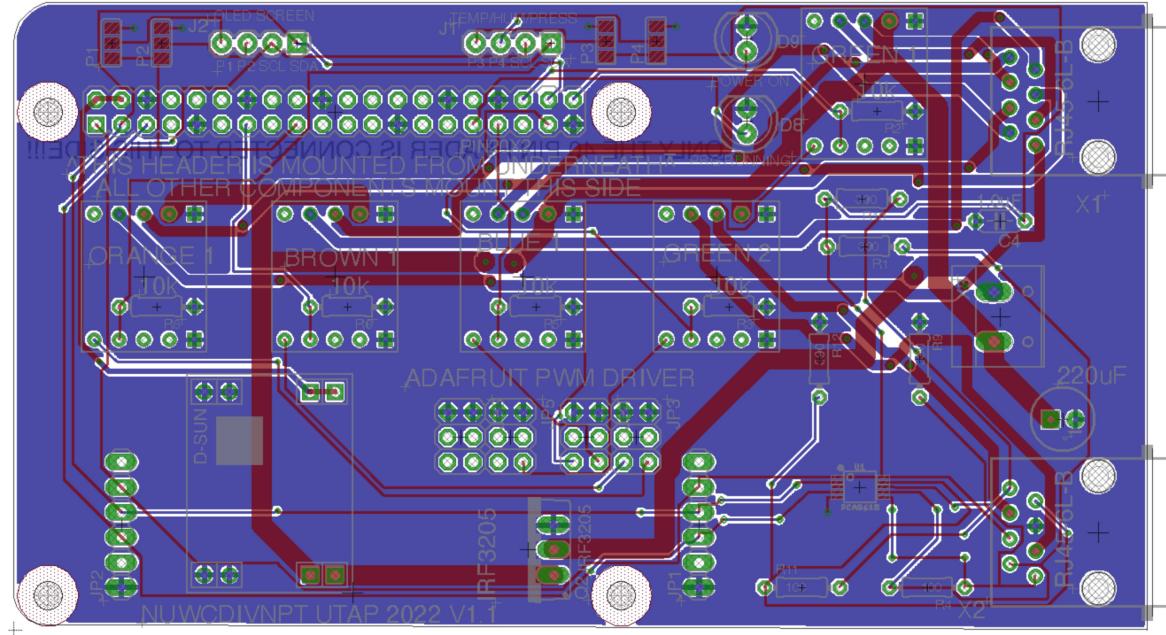
Since we're using the RPi, it seemed rather obvious to design a circuit board that would mate to the 40 General Purpose Input/Output (GPIO) pins on the RPi (see figure 17). This allows each of the pins to be routed to other devices on the PCB (the PWM driver and the motor drivers) to control the power to the motors. On this newly designed board, header pins (essentially sockets) are mounted that will then accept the motor drivers and pulse width modulation (PWM) board as well as the sensors that we will use to display information about the environment.

5.1 Pinout

The Raspberry Pi has a somewhat confusing pinout structure. The header pins have several different numbering systems, depending on how a user intends to access them. For instance, the pins can be numbered in an intuitive way from the top row such that the first pin is 1 and the one next to it is 2. The next row is 3 and 4 and so on. Makes perfect sense, right? However, to use the pins as General Purpose Input Output (GPIO), the user needs to access the Broadcom BCM2837 system-on-chip (SoC) processor, which includes the four high-performance ARM Cortex cores. This chip handles all the input/output for the RPi. Still makes sense, right? Well, the pin numbers on the Broadcom chip DO NOT correspond to the actual pin numbers of the header pin. Referring to figure 17, it's clear that care must be taken when defining a pin to use. For the UTAP project, the Broadcom naming convention is used, which is the *NAME* column in figure 17, NOT the *Pin#*. Notice, for instance, that GPIO19 isn't

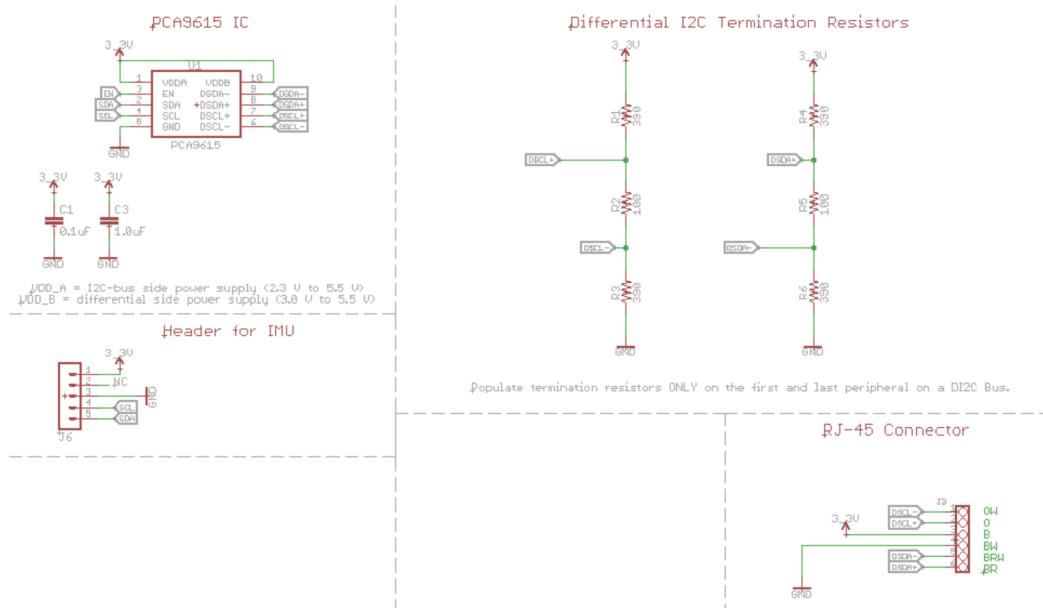


(a) Circuit diagram (schematic) for the daughterboard.

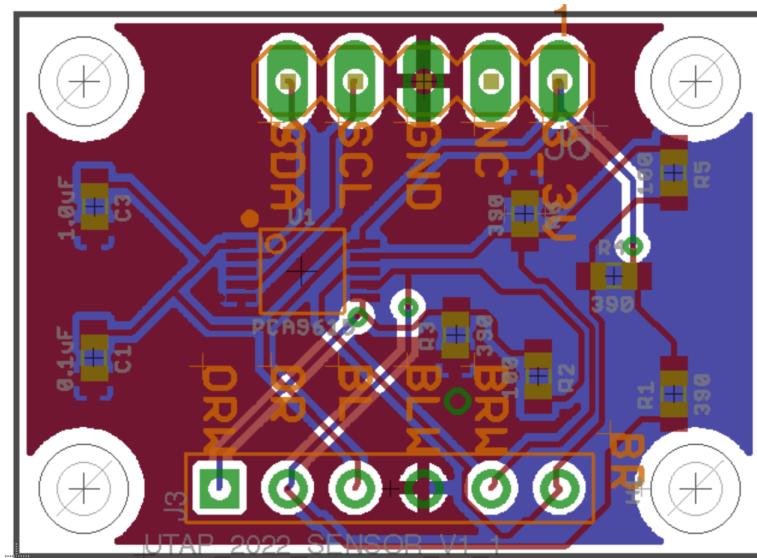


(b) The PCB that the schematic produces.

Figure 11: Daugterboard schematic and printed circuit board.



(a) Circuit diagram (schematic) for the daughterboard.



(b) The PCB that the schematic produces.

Figure 12: Daugterboard schematic and printed circuit board.

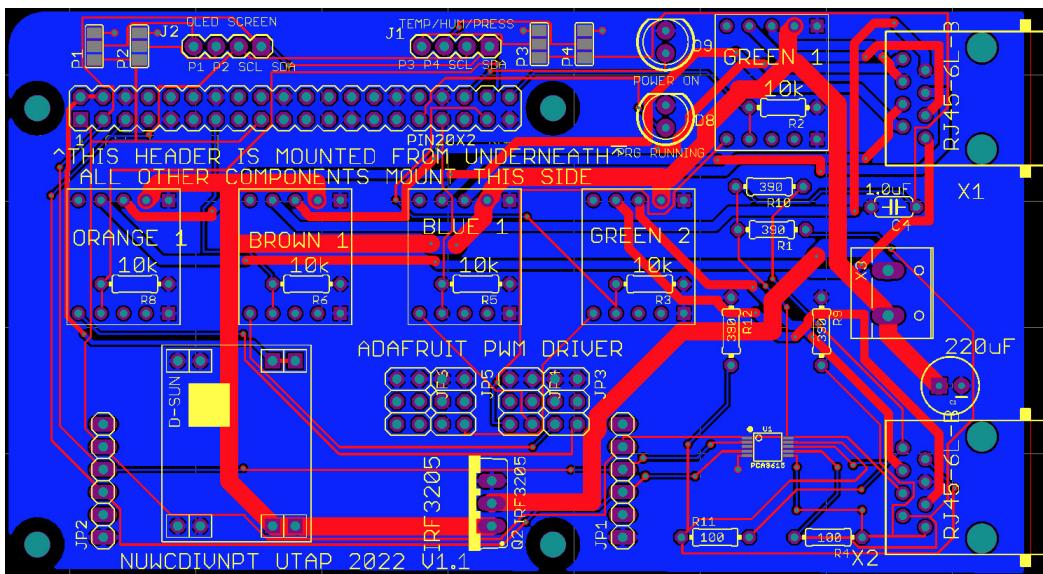


Figure 13: Superimposed layers of the PCB sent to the manufacturer for fabrication.

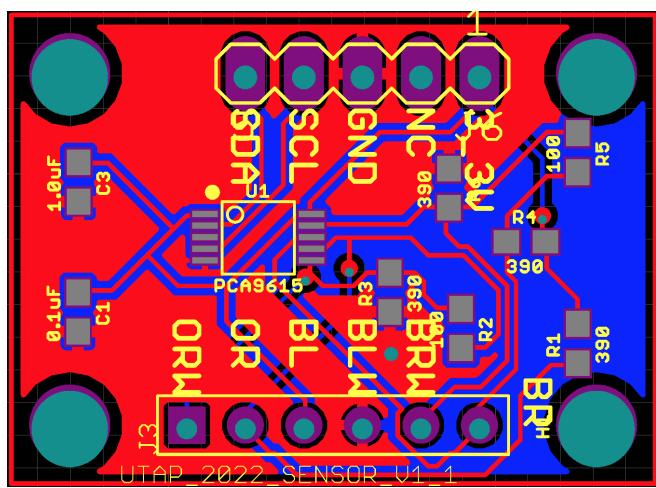
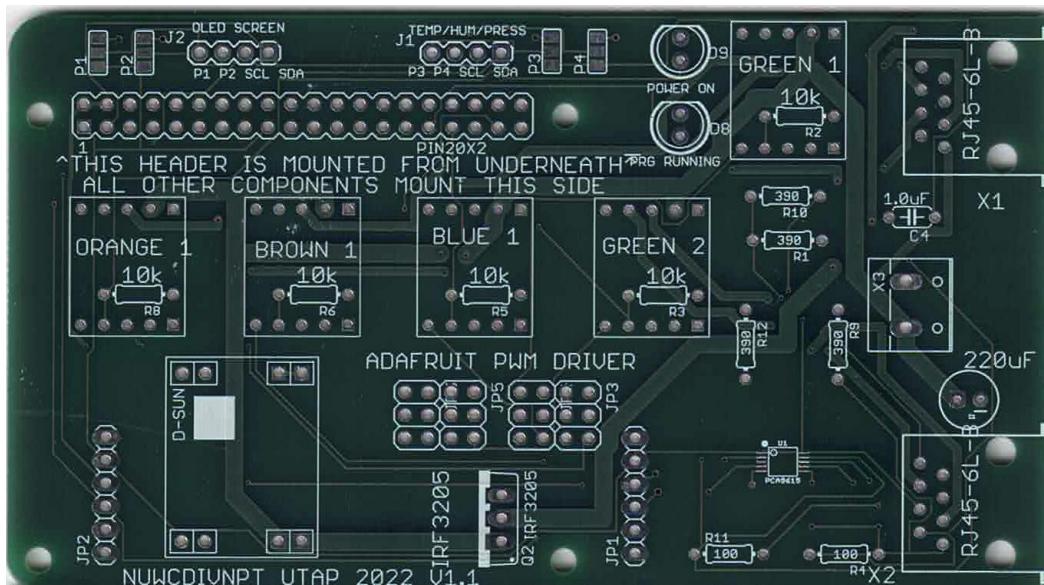
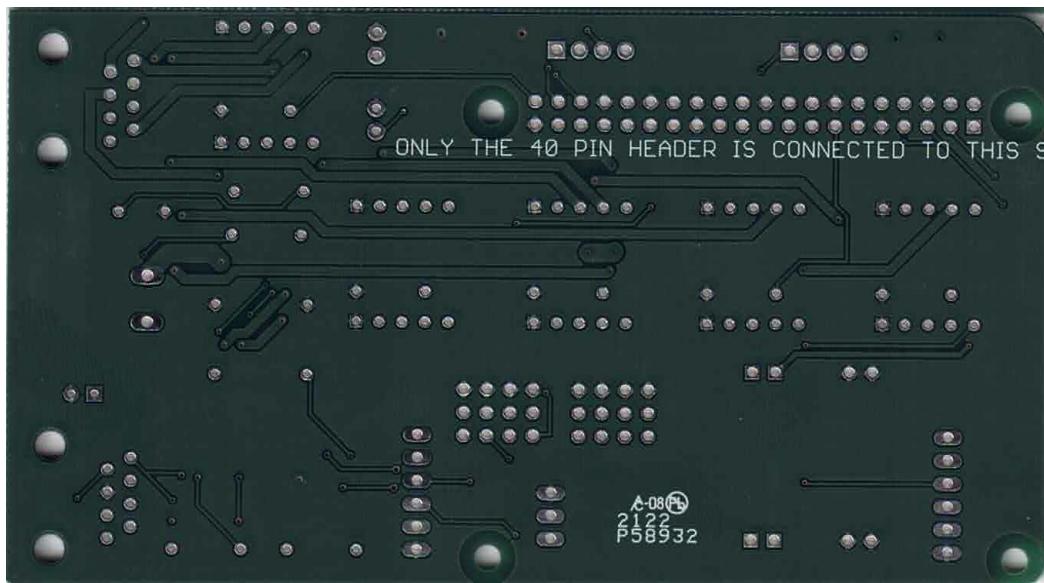


Figure 14: Superimposed layers of the PCB sent to the manufacturer for fabrication.

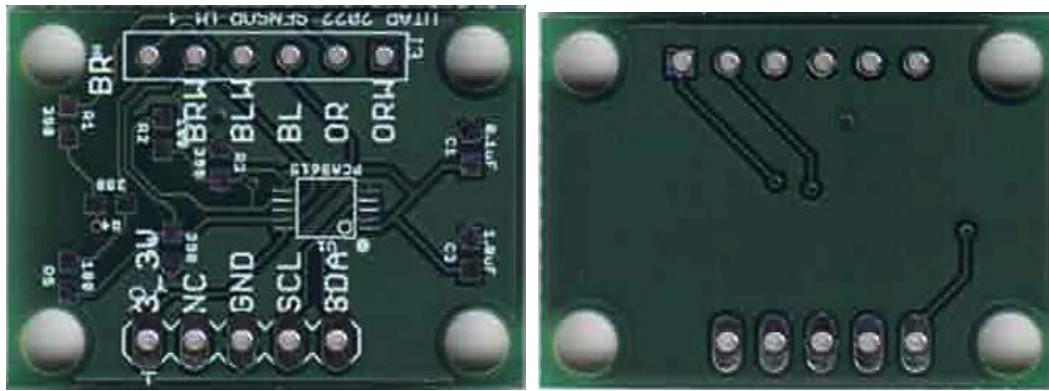


(a) Front side of the PCB.



(b) Back side of the PCB.

Figure 15: UTAP 2022 Printed Circuit Board (PCB).



(a) Front side of the sensor PCB.

(b) Back side of the PCB.

Figure 16: UTAP 2022 Sensor Printed Circuit Board (PCB).

on pin#19 but rather on pin#35. Overall, this has limited effect on our build, since all the connections are already hardwired into the printed circuit board. However, should you choose to continue working with the RPi after the apprenticeship, it is something to keep in mind.

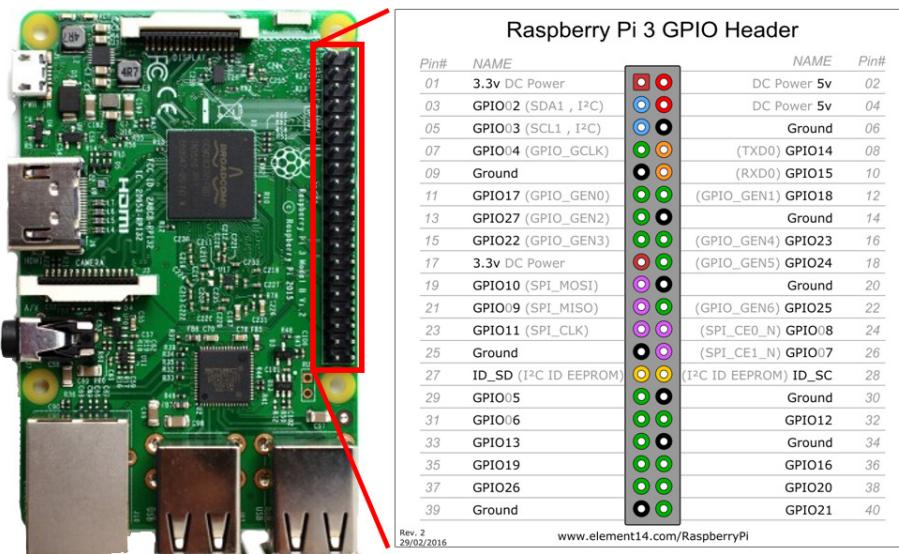


Figure 17: This pinout is valid for both RPi versions 2 and 3.

6 Adafruit PWM Driver

For all the power the RPi has as a computer, the GPIO pins lack several functions common on most microcontrollers. This isn't really surprising - after all, the RPi is a computer not a microcontroller. However, because it's a computer, it can overcome most, if not all, of these shortcomings. The most immediate limitation for our project is that the RPi has only 1 hardware PWM pin. Since each motor needs to be speed controlled, and there are 8 motors, it would be really helpful if the RPi had 8 PWM

pins.

Pulse Width Modulation (PWM) is a technique for delivering variable power to devices that require a certain amount of voltage (say, 12 v) to activate. For instance, to provide half power to a 12V motor that only turns on at 12V, supplying 6V won't work - the motor wouldn't even spin, let alone spin at half power. What is done instead is to provide 12V and 0V in equal proportions (pulses), effectively providing 12V only half the time. This is called a 50% duty cycle and it is accomplished by modulating (changing) the width of the 12V pulse. For full power, the pulse is infinitely long, i.e. it stays at 12V. The PWM can be tied to the joystick to match the PWM width to the amount of movement in the joystick, hence joystick controlled variable speed motors.

The RPi does have hardware PWM available. As previously mentioned, the problem is there is only one *hardware* PWM pin. This means the pin is configured with hardware (transistors) to provide a variable pulse width through the pin. But it's also perfectly reasonable to make pulses using software, by setting a pin high (5V or 3.3V for instance) for a period of time, then setting it low (0V) for a period of time. While this is a reasonable solution (in fact it's done all the time), it's not ideal - there are delays and interrupts involved and it makes the code more complex than it is already. And since the RPi is a computer, it is often busy managing its own internal timing requirements.

Problem: we need as many as 8 PWM signals (for potentially 8 motors) but we have only one PWM pin on the RPi. Solution: Adafruit's PWM Driver Board, which can control 16 PWM signals over a data transfer protocol called I2C². The RPi supports I2C and the PWM driver supports I2C. We simply program the RPi to read the USB gamepad joystick and send that information to the PWM driver, which will tell it how to generate the 8 PWM signals we need. Each PWM signal has its own address (conceptually no different than an Internet address) so we can send specific commands to specific PWM addresses to control them individually. Mind blown? Don't worry, we'll go over this during one of our instruction sessions.

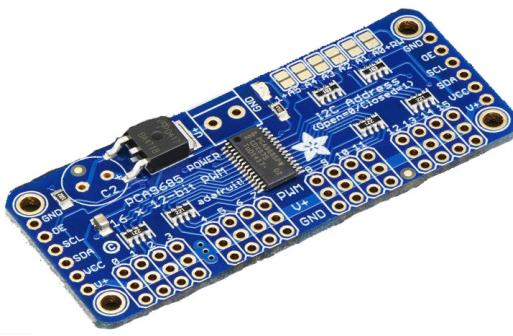


Figure 18: The Adafruit 16 channel PWM Driver Board. We will only be using 8 channels.

²Inter Integrated Circuit communication protocol was developed by Philips in 1982. It is an easy way to communicate information between 2 different devices on the same circuit or communication bus.

7 Motor Drivers

The motor drivers are responsible for controlling the amount of power delivered to the motors, as well as which direction they spin. The MAX14870 (Maxim Integrated Co.) accepts a number of different inputs but our application only uses four: the PWM input, the direction input and power and ground for the motor (figure 19). The PWM comes from the Adafruit PWM driver, while the direction control comes from one of the pins (GPIO) on the RPi. When the joystick is moved from the dead zone³, a value proportional to the displacement of the joystick is generated. Since the PWM has 12 bits of resolution (meaning it has 4096 (2^{12}) levels from off to on), numbers from 0 to 4095 represent the levels from fully off (0) to fully on (4095). For instance, if the gamepad joystick is moved halfway between the center position and fully engaged, the value from the joystick will be 2048, and the pulse width proportion will be 50%, or half power. This pulse waveform goes into the MAX14870 where the H-bridge⁴ pulses 'on' half the time and 'off' half the time, creating the effect of half power. You most likely performed this exact same technique when driving your SeaPerch for the first time, essentially toggling the switches back and forth (pulsing) to change the speed of the vehicle to gain a bit more fine control.

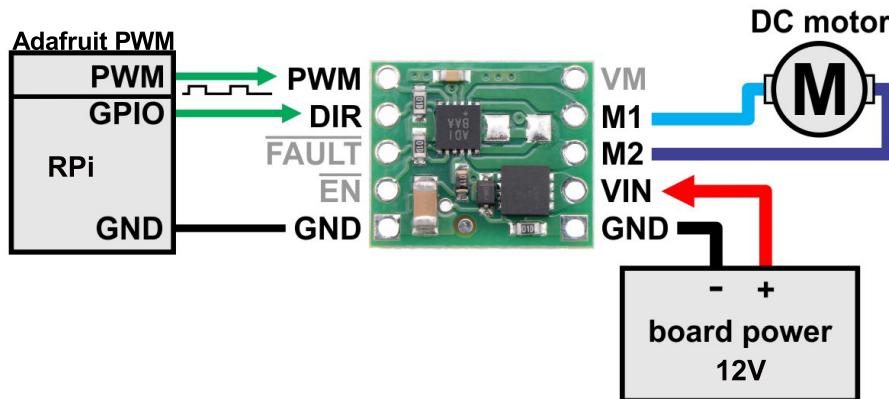


Figure 19: The Motor Driver board and PWM interface diagram. From <https://www.pololu.com/product/2961>

It is instructive to note that this technique for driving a motor via PWM is necessary for motors that have a so-called turn-on voltage. As previously suggested, many motors need a minimum of 12V before they are even able to start spinning. Therefore, delivering 6V will not spin the motor at half speed. This is the critical distinction between the PWM method of varying power versus reducing the voltage value available to the motors.

The motor drivers are supplied to you with 2 5-pin male header pins already attached. You simply need

³A dead zone is an area around the center position of the joystick that insures an "OFF" state. It's necessary because a joystick will never be able to return to the EXACT center position. To insure the center position is truly off, an area around the center large enough to accommodate any slight shift from the center is established.

⁴This is the circuit that controls how power is delivered to the motor. It's called an H-bridge because of the shape of the transistor layout.

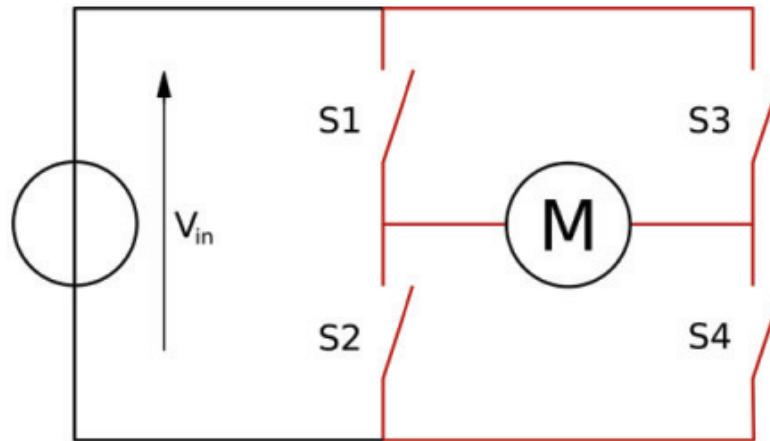
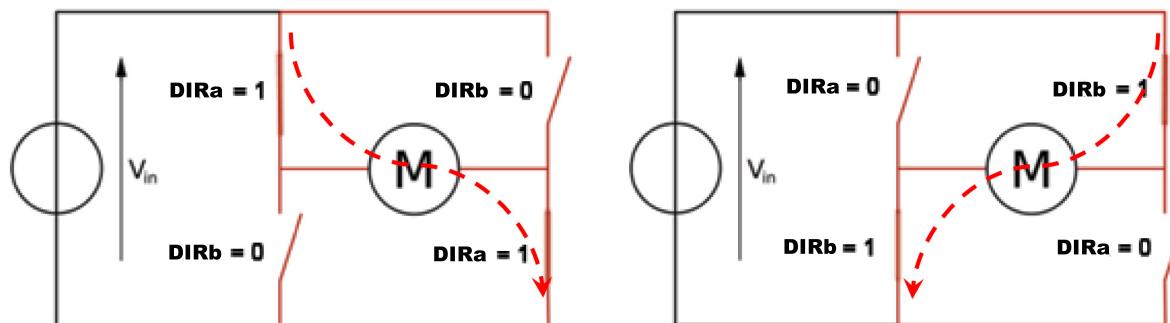


Figure 20: H-Bridge schematic. The center portion with the motor resembles an 'H'.



(a) When DIRa switches are set to 1, they close and the motor spins in the forward direction. The other switches (DIRb) receive the NOT ($1 \rightarrow 0, 0 \rightarrow 1$) of DIRa.

(b) When DIRb switches are set to 1, they close and the motor spins in the reverse direction. Likewise, the other switches (DIRa) receive the NOT ($1 \rightarrow 0, 0 \rightarrow 1$) of DIRb.

Figure 21: Note when two switches are closed, the other two MUST be open, otherwise the motor won't be able to spin at all.

to solder the corresponding 2 5-pin female headers in the part of the board that shows the footprint (outline) of the motor driver board (figure 22). **IT IS CRITICAL THAT THE MOTOR DRIVER BE INSTALLED IN THE RIGHT ORIENTATION. IF IT IS INSTALLED UPSIDE DOWN, IT WILL BURN UP!!!!** When it's time to mount the motor driver onto the female header pins, refer to figure 29.

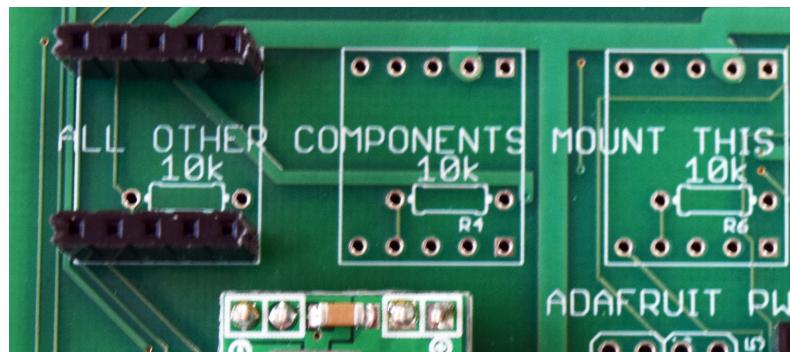


Figure 22: See figure 29 before attaching the motor driver.

8 The Gamepad

The Logitech F310 USB gamepad looks like most modern gamepad controllers. It has all the components we need (quite a bit more than we need, actually) with a fairly straightforward interface. That is, the code to pull information from the gamepad (the joystick position, which buttons have been pressed, etc.) is readily available.



Figure 23: The Logitech F310 USB gamepad.

The code to read the gamepad for this project has been cobbled together from a number of different sources, the most principal of which is from (`js-dev.py`) available from <https://gist.github.com/rdb/8864666>. While this may seem like cheating, it's actually a pretty common way of writing code. There is no need to rewrite code that has already been written and made available for sharing under the concept of *Open Source*. You may need to modify it (slightly or heavily) but it's often more efficient to modify already existing code than it is to write code from scratch. However, it's always good form to reference the sources when you use someone else's work. It's the least you can do for the resulting workload reduction. Plus, since no one is getting compensated for the work they did to write the code, this is the only form recognition they receive.

9 Pin Mapping

The RPi GPIO pinout was discussed earlier. Figure 24, however, shows which GPIO pins control which components on the PCB. For instance, GPIO pin 16 turns on an LED (furthest to the right) when the program is running, and GPIO4 is the direction pin for the ORANGE wire connected to RJ1. Recall from the SeaPerch build that each Ethernet cable has 4 twisted pair of wires: one orange pair, one brown pair, one blue pair, and one green pair. This is how we will identify which motor to turn off and on.

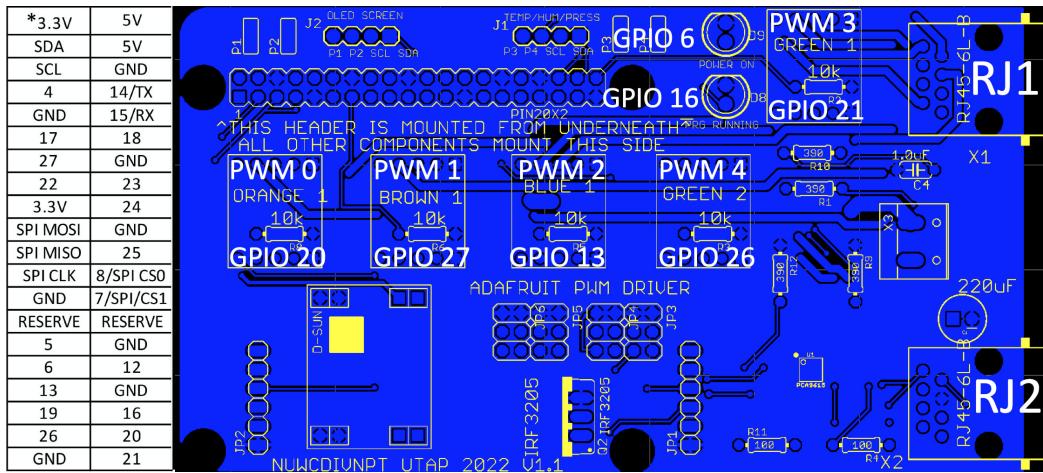


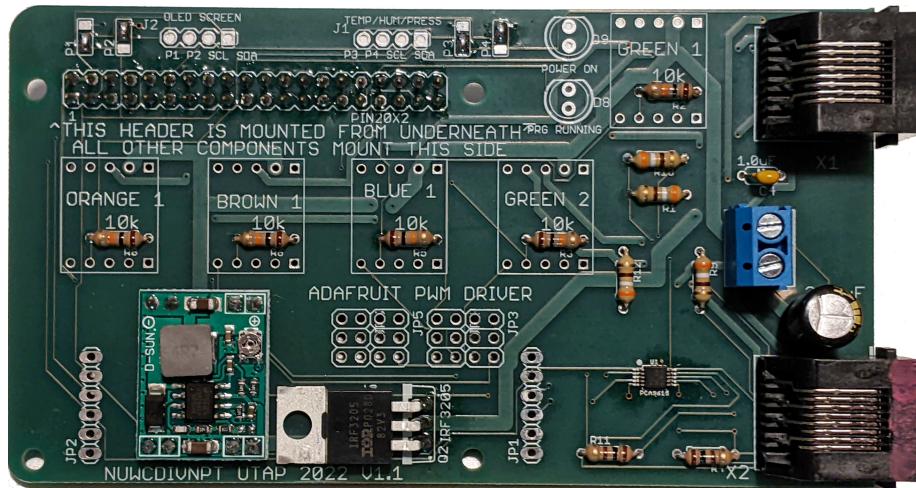
Figure 24: Mapping of the GPIO pins and PWM pins to the motor drivers. The asterisk marks the location of pin 1.

10 Assembling the Circuit

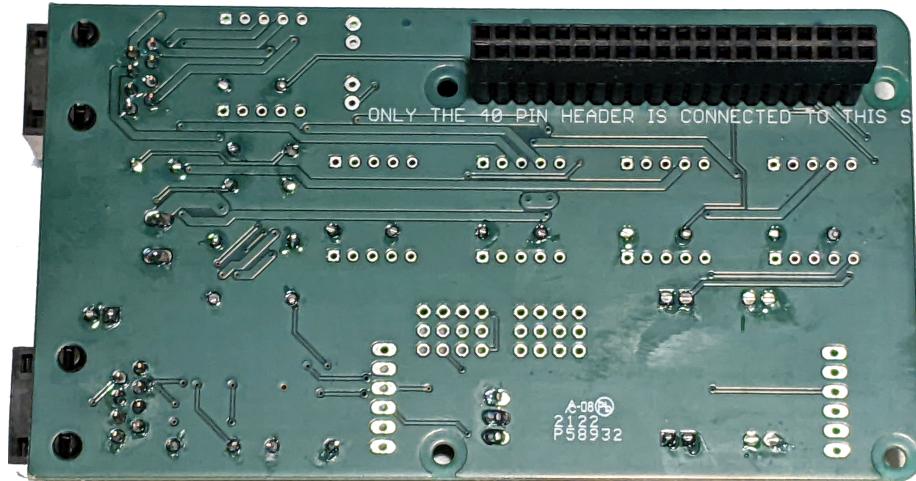
It turns out that the assembly of this circuit is really pretty straightforward. For the most part, it's just a number of female header pins, a few resistors, some LEDs, a capacitor, a couple RJ45 jacks, and a power terminal. Because changes were made to accommodate the underwater inertial navigation sensor, some of the board is already pre-populated (Fig. 25).

The principal reason these parts are pre-installed is due to the small chip that requires special mounting techniques (Fig. 26). This type of mounting is called Surface Mounting and any device mounted in this way is an SMD - Surface Mounted Device. And in order to make sure it was mounted correctly, the other components were added to verify that the chip would perform correctly. There are still a number of headers and parts that need to be installed, so you'll have plenty to solder.

The printed circuit boards have what is known as a silk screen (white printing on the board) to guide you to put the right part in the right place. **PAY ATTENTION TO THE TEXT!** In addition to text, the outline of the part is printed. Simply put the leads, or legs, of the part in the holes of the PCB. For some things like resistors, the orientation of the part is not important - it can't be put in backward. Other things, like electrolytic capacitors, as well as integrated circuits (chips) need to be put in the correct way because they have a polarity - meaning a 'plus' side and a 'minus' side. Think of it as putting batteries in a device with the plus and minus sides lined up with the pictures on the battery tray.



(a) The top of the board will look like this when you receive it.



(b) The 40 pin header as seen from the bottom.

Figure 25: You will receive the PCB with these parts pre-installed.

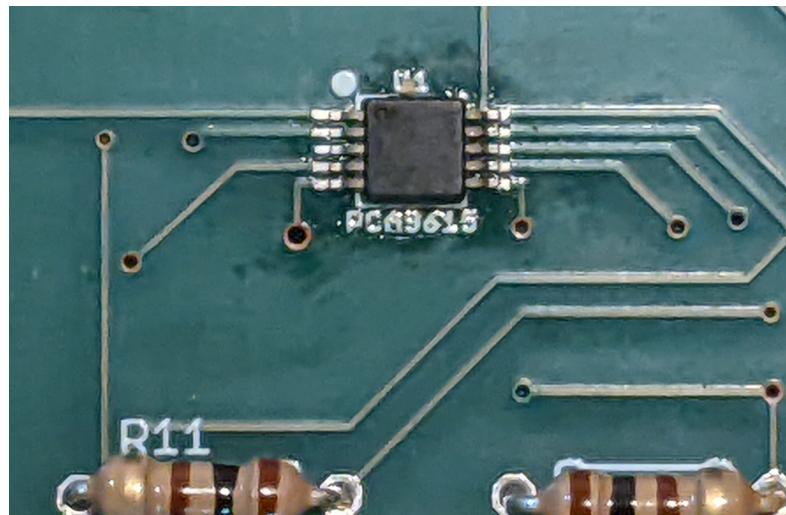


Figure 26: Mount the female header pins.

Add the 5-pin female headers for the motor drivers (red arrows, figure 27, repeat for all 8 drivers), the 6-pin female headers for the PWM Driver Board (yellow arrows, figure 27), and the 3×4 female headers for the PWM Driver Board (orange arrows, figure 27, only one shown). FOLLOW THE PICTURE IN figure 27!!!

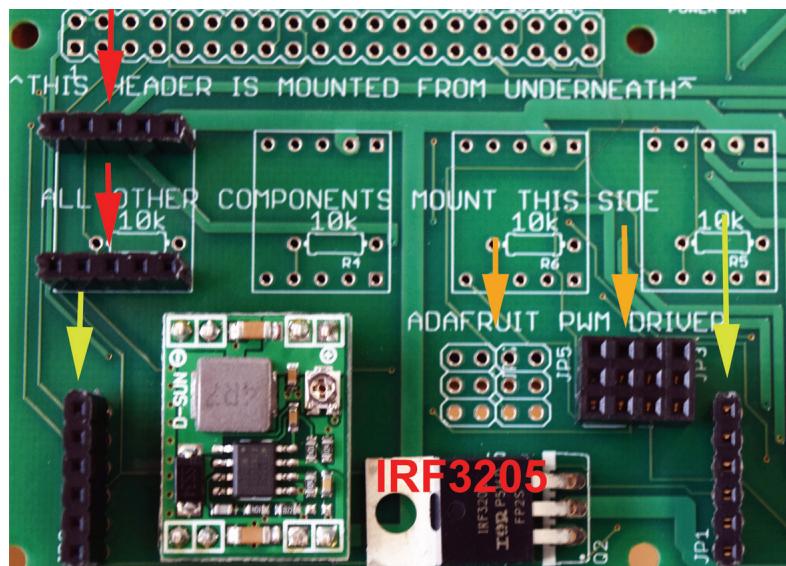


Figure 27: Mount the female header pins.

You can now attach the Adafruit PWM board to the PCB (figure 28) and the motor drivers (FOLLOW THE GUIDELINES ON THE NEXT PAGE!!!!).

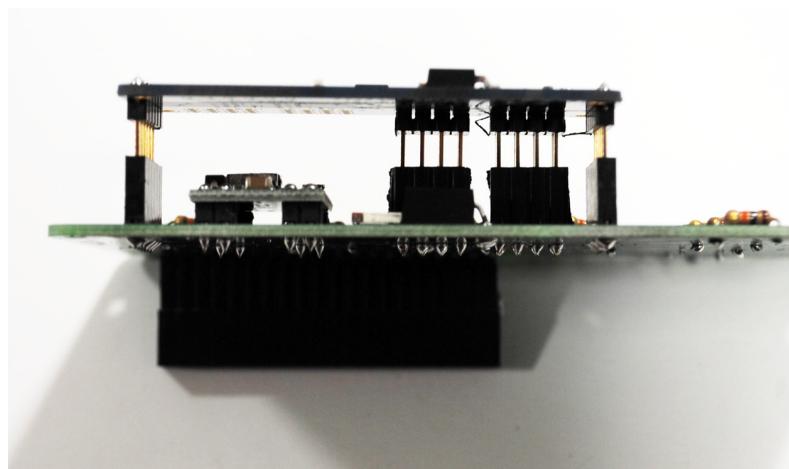


Figure 28: The PWM driver board mounted to the PCB.

DO NOT INSTALL THE MOTOR DRIVERS UPSIDE DOWN!!!!

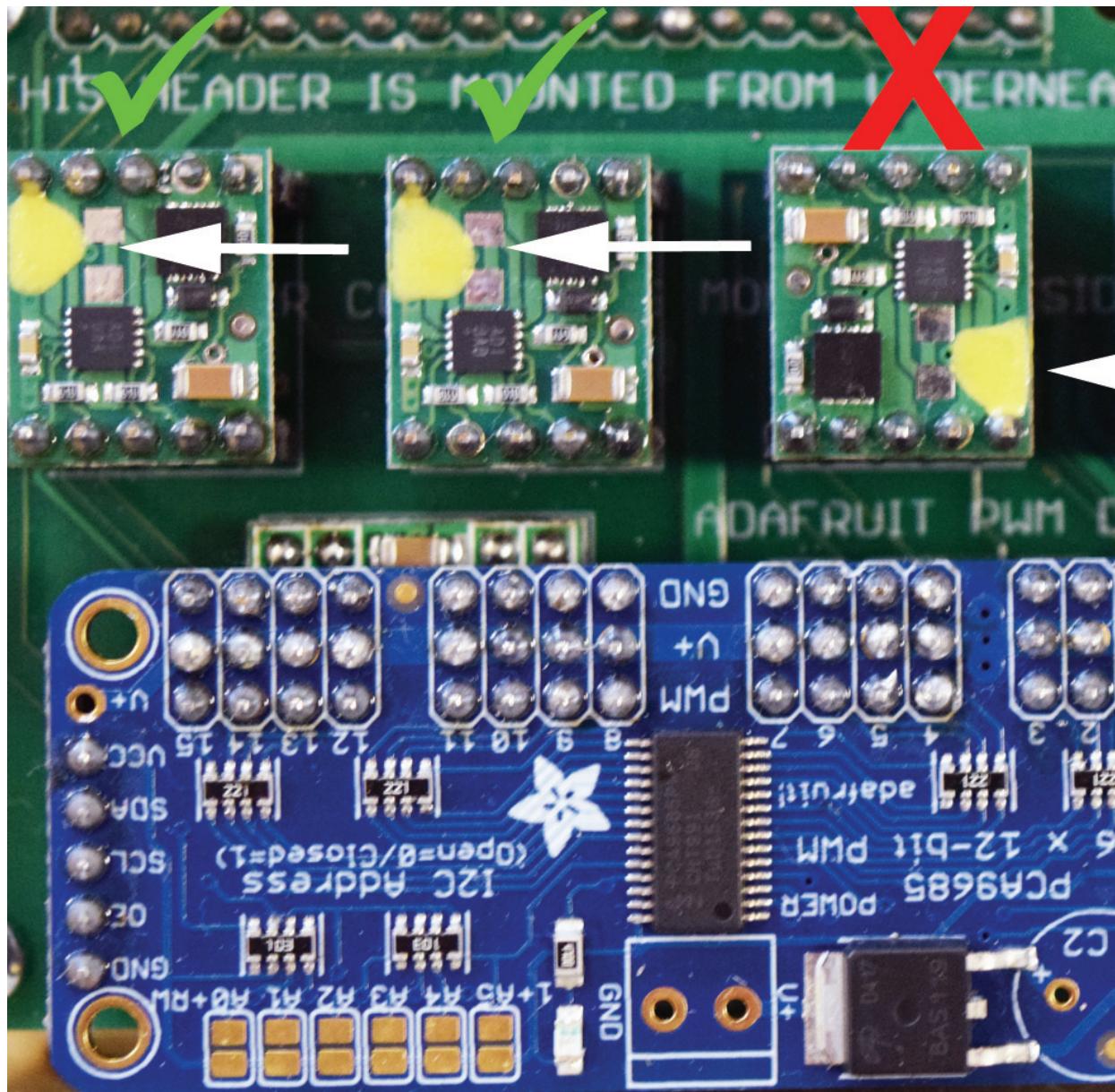


Figure 29: Look closely at the arrows!!! The driver should be inserted so the colored marker (yellow in this case) is in the upper left NOT the lower right.

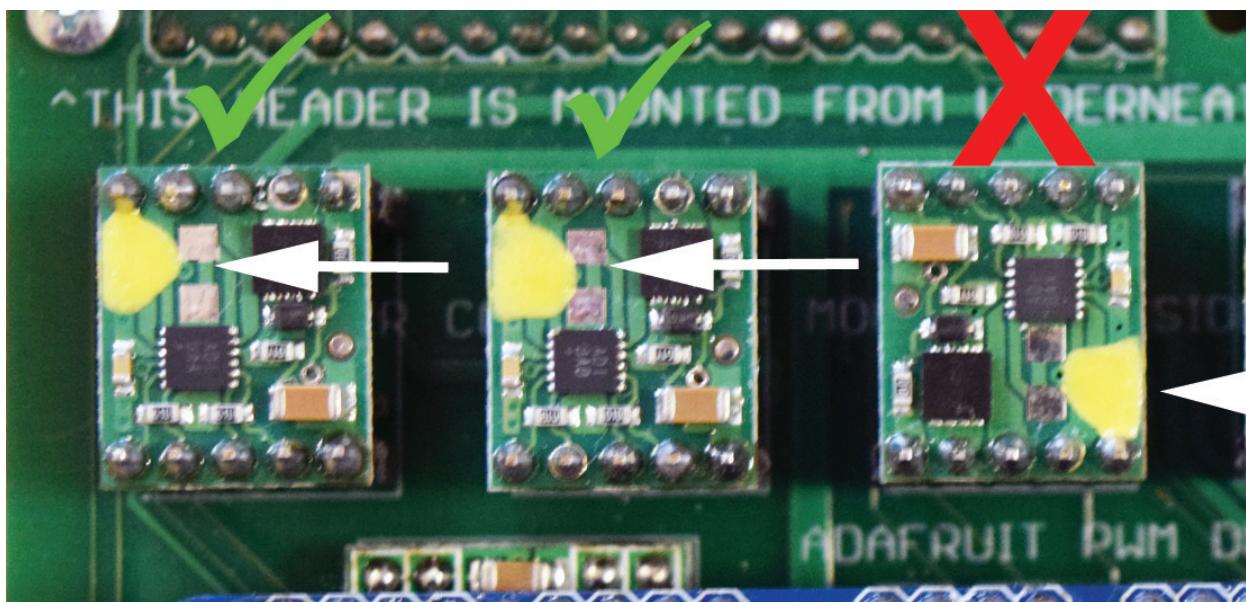


Figure 30: Look even MORE closely!!!!

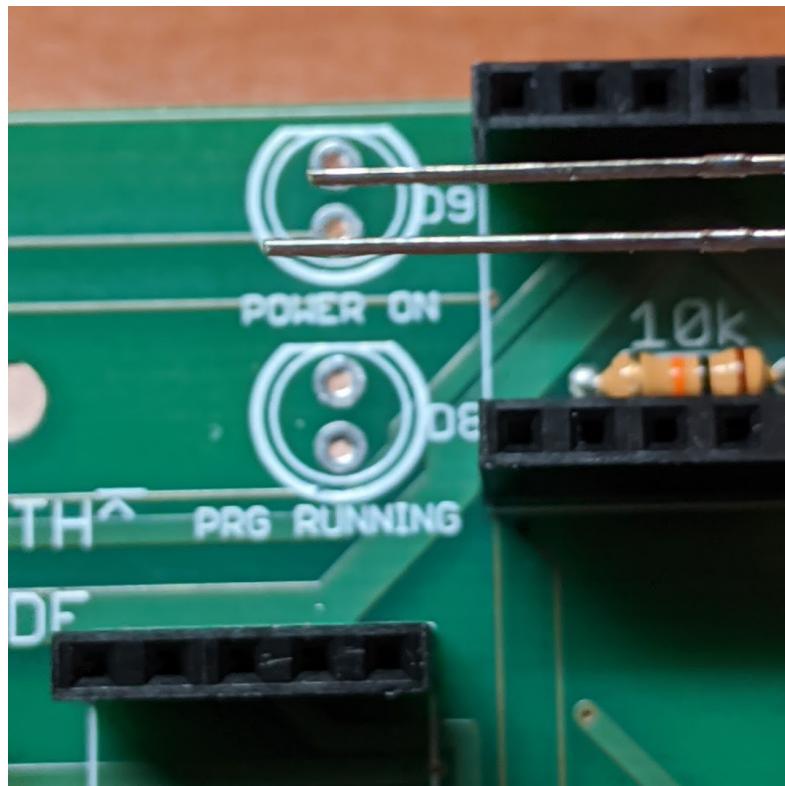
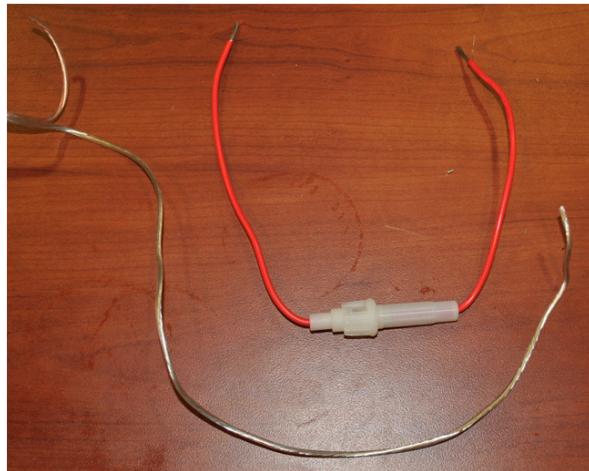


Figure 31: The long leg is the positive leg and the short leg is the ground (negative) leg. The short leg goes in the hole closest to the flat edge of the outline.

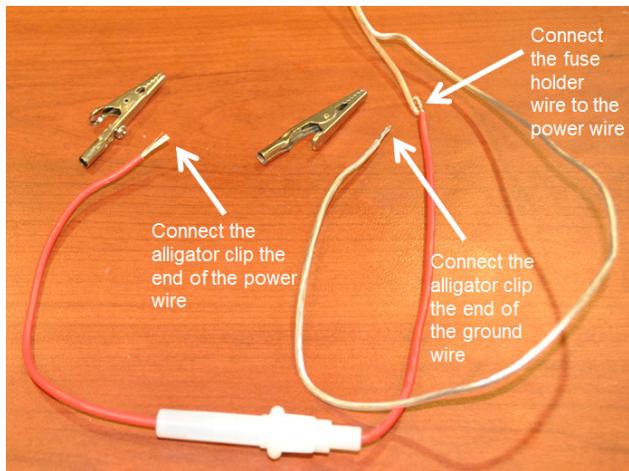
11 Power Cord

SOME POWER CORDS ARE ALREADY PREPARED. YOU WILL ONLY HAVE TO DO THIS IF YOU DID NOT RECEIVE A PRE-ASSEMBLED POWER CORD.

Do you remember putting the alligator clips on the power cord when building the SeaPerch? The same thing needs to be done for the new controller. The difference is that we need to put an in-line fuse on our cord. From the "power" side of the power cord, cut the wire a length equal to the length of the fuse cable (figure 32). Don't forget to put the fuse in the fuse holder (figure 33)!



(a) Cut out a section of the power side of the cable so your power cord is the same length on both sides.



(b) Attach the alligator clips the same way you did for the SeaPerch.

Figure 32: Installing an in-line fuse.

To avoid the possibility that some of the strands of wire from the power cord (speaker wire) could touch, you can perform a technique known as tinning. This essentially turns a stranded wire into a solid wire so that none of the strands get frayed. Simply twist the strands of wire at the end of the cable, heat the wire, and allow solder to wick into the strand (figure 34). Ask a mentor for assistance if you have trouble.

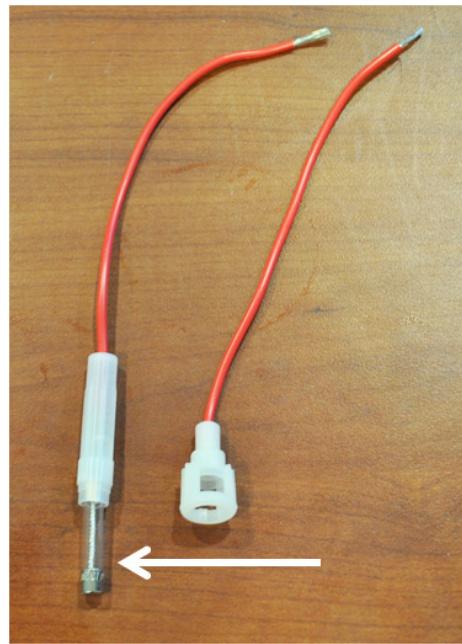


Figure 33: The fuse holder twists apart. Install the fuse and twist the fuse holder until it locks in place.

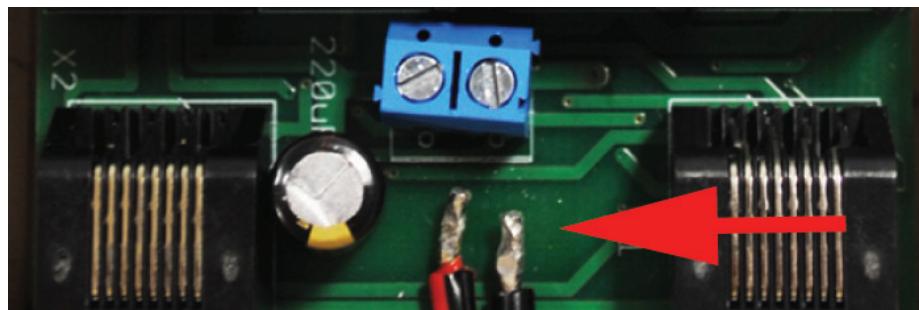


Figure 34: Melt solder into the end of the stranded wire to prevent strands from the power side of the power cable from touching the ground side of the power cable.

12 Completed Daughterboard

When the circuit board is completed it should look like figure 35. **Take a small piece of electrical tape and cover the back of the OLED screen!!**

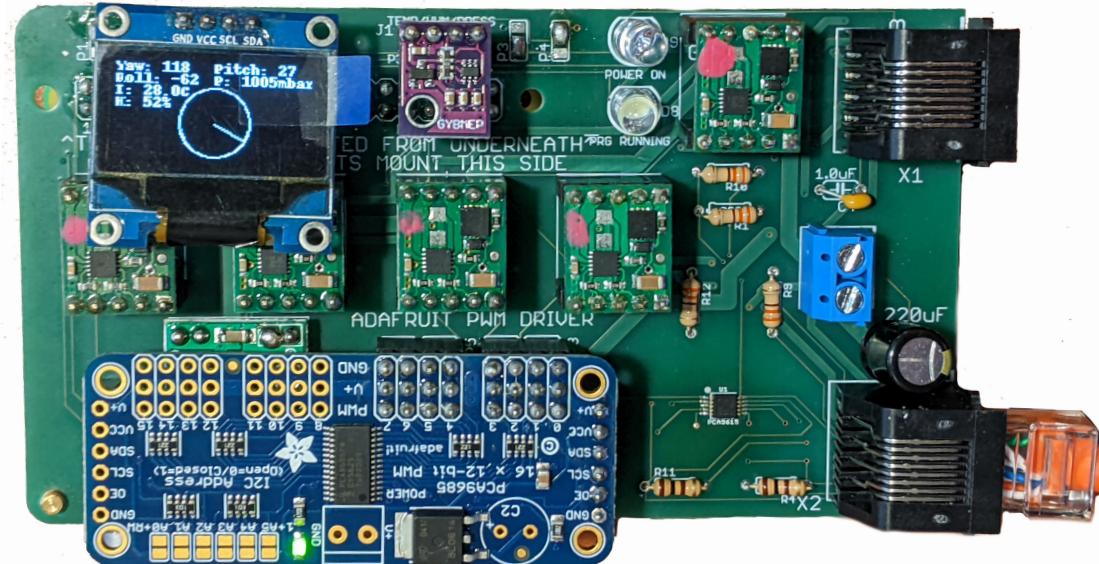


Figure 35: The completed circuit board.

13 Power

Before attaching the daughterboard to the RPi, it is a good idea to verify that the step down voltage regulator is actually producing a 5V reference voltage for the RPi. This was initially checked for all boards to prevent the RPi from being destroyed by providing too much voltage. However, things change so it's a good habit to make sure the voltage is correct. Anywhere in the range of 5.0 to about 5.3 is perfectly fine.

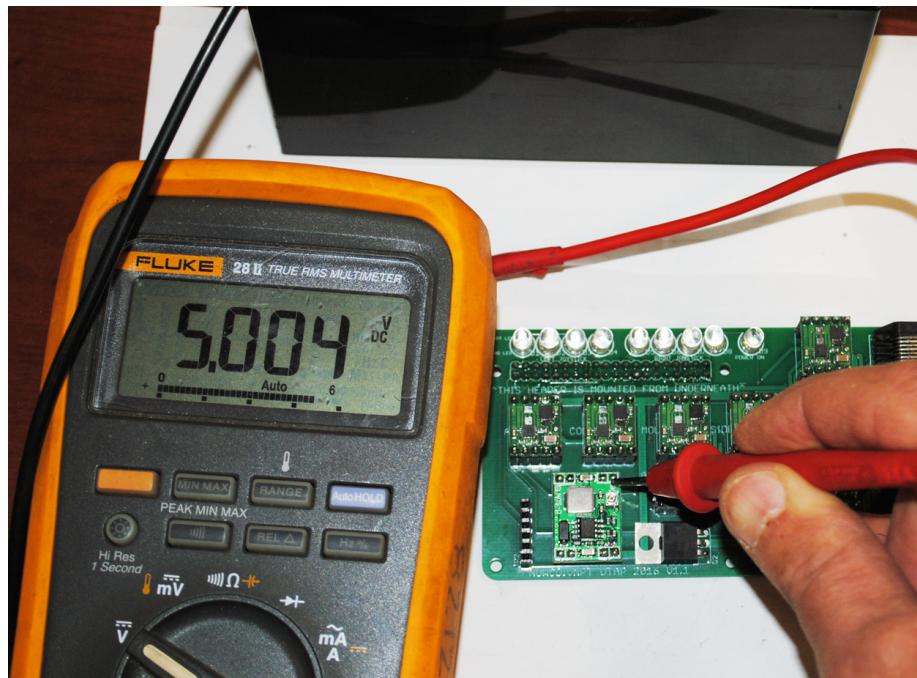


Figure 36: Use a multimeter to test the voltage. Ask a mentor if you need assistance.

14 Connecting Daughterboard to the Raspberry Pi

Now that power to the RPi has been verified to be a stable 5V, the daughterboard can be connected to the RPi. First, make sure there is no power connected to either the RPi or the board. Then, simply line up the female header pins under the daughterboard with the male header pins on the RPi. To keep them from coming apart, insert spacers between the two boards. Note that there are holes that are aligned between the two boards.

Insert the supplied spacers between the holes and attach with the supplied screws from the top only (figure 37). You'll need to remove the PWM board temporarily to access the top of the spacer so do not connect the bottom at this point.

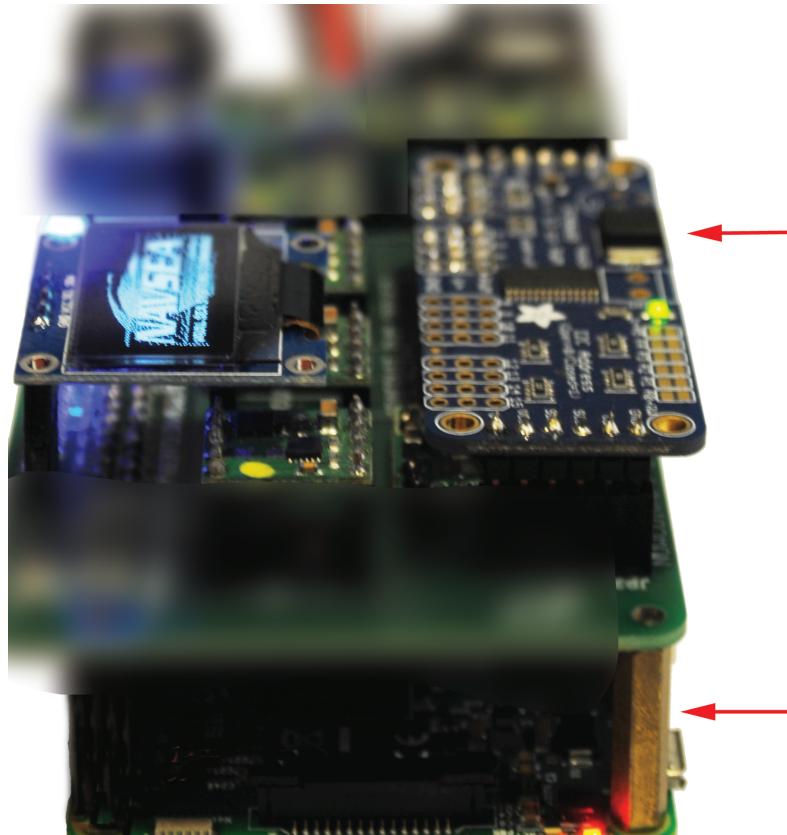


Figure 37: Attach 2 spacers with small screws - one is under the PWM board so you'll need to remove the board.

We have designed and fabricated custom boxes for this program (figure 38.) The entire circuit fits nicely into the box. **Be sure to slide the circuit all the way forward so the RJ45 jacks fit snugly in the openings.** This will make it much easier to insert the screws in the

bottom spacer. Additionally, there is an acrylic shelf that prevents the USB from the gamepad from touching the underside of the RPi and shorting out the whole circuit.

First, you'll need to detach the power cable.



Figure 38: The entire circuit is placed inside the custom box.

Now, attach the provided long screw through the bottom of the box and into the spacer (figure 40). If the board is well aligned, the screw should be able to be hand tightened. If not, you may need to wiggle it, just a little bit.

Finally, reinsert the power cable through the hole on the box marked `Power` and screw into the power terminal. To provide some strain relief for the power cord (so it doesn't yank out of the power terminal when you grab the wires), place a zip tie around the wire and cinch tightly.

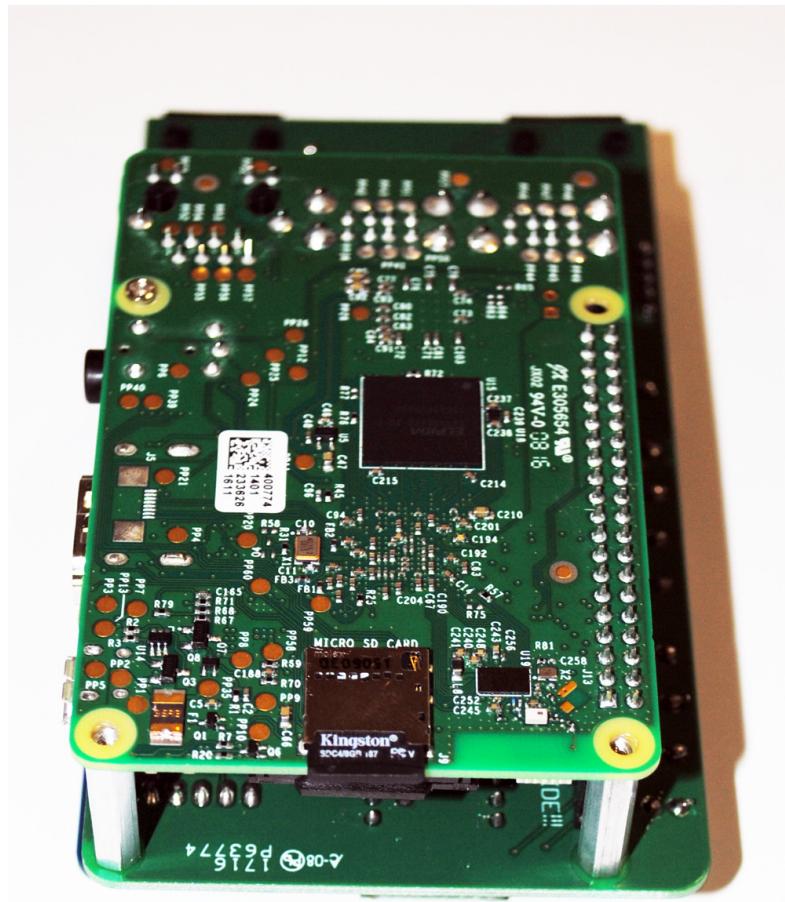


Figure 39: The board will be mounted to the box do not install screws at this point.

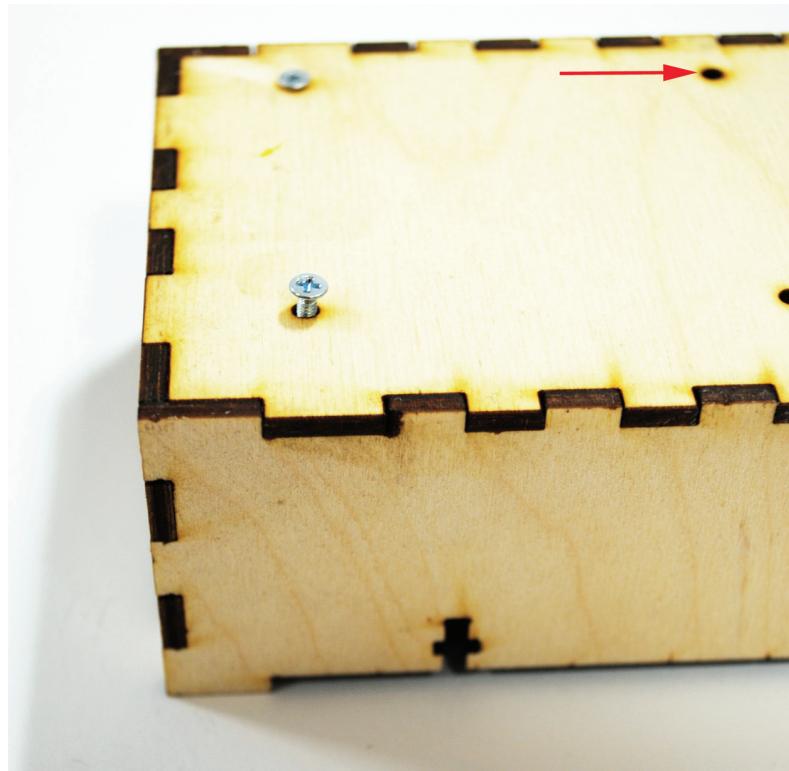


Figure 40: Once the board is aligned in the box (the RJ45 jacks will be all the way forward) attach screws through the box, into the spacer.

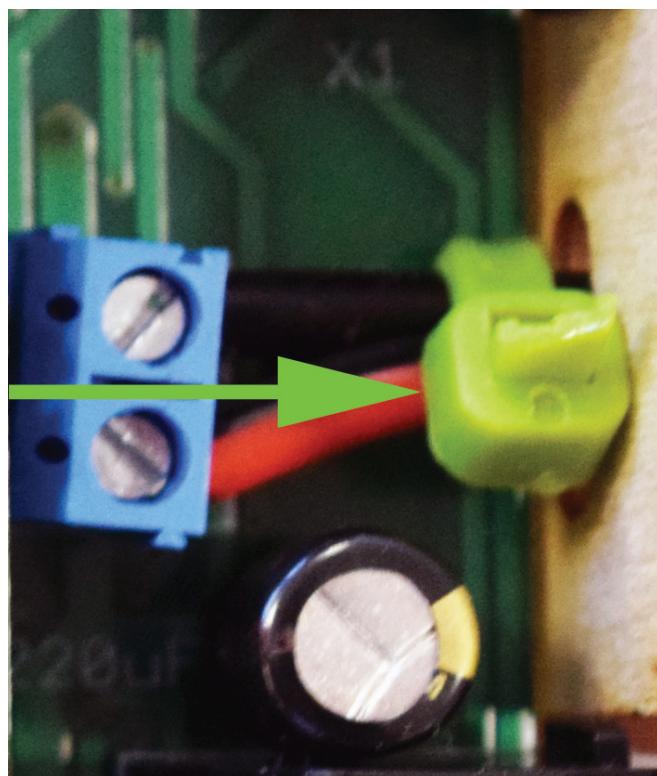


Figure 41: Make sure the zip tie is pulled tightly.

15 Code Overview

While we'll be spending some time during the apprenticeship going over the code, there are a few items to address here for reference. First, a copy of the BASE code is available on a GitHub repository at <https://github.com/jdicecco/UTAP>. (We'll be going over how to get a copy of the code onto your Raspberry Pi in the lecture). Note the use of the word BASE. This code has been constructed to provide you basic joystick control of your newly designed vehicle. The code assumes that the vehicle maintains the same motor structure as the basic SeaPerch, i.e. the motors attached to the green wires are on the right of the vehicle, the motors attached to the blue wires are on the left of the vehicle and orange is used for ascent and descent. Of course, if you've chosen to use all 6 motors (4 on one Ethernet cable, two on the other) you'll have two motors connected to green wires, two motors connected to blue wires, and one motor each connected to the orange and brown wires. Usually, one should avoid assuming how to place the motors on the vehicle. However, in this case, it really doesn't matter because this is all controlled in software. And software can be changed very easily.

The code accounts for reading the values from the gamepad - the joystick values, the button values, and the hat values. Currently, only the joystick values are being used in the code. But again, this is software, so that can, and should, change. The code reads the value from the joystick, in the range of -32767 to 32767. But the software library that controls our PWM board is expecting an input in the range of -65535 to 65535. In hexadecimal representation 65535 would be 0xFFFF. You'll see this in the code in some spots - don't worry, we'll be going over all this in the lecture portion.

You have been provided base code that will allow you to control your vehicle in what it referred to as Tank Drive. That is, the left joystick controls the left side, the right joystick controls the right side, just like the SeaPerch controller. Now, of course, it has speed control.

The up and down thrusters are controlled by the trigger joysticks in the front of the controller and are also speed controlled.

Here's the really fun part: you can map any pin on the joystick to control any motor you want on your vehicle. If you want to use the hat for strafing (move from side to side) for instance, no problem. Since you're writing the code, you can make it do anything you want ... within reason.

16 Running the Code on Raspberry Pi

You can power the Raspberry Pi at this point with EITHER the battery or the USB port from your PC but NOT both!!!! The 5V regulator on the board is NOT at the same exact value as the 5V from your USB port.

In order to modify and run the code while developing the design, some simple steps are necessary

to open the code, change it, and run it. Of course, you need to supply power to your RPi board first.

First, we need to make a directory on the desktop of the Raspberry Pi. You are no doubt used to right clicking and making a folder. It turns out you can do it with a command as well. In Linux, that command is `mkdir name`, where name is the folder name you'd like to use. Change your working directory with the `cd` command to the desktop. Once there, make a directory called RPi (figure 42).

Next, we need to make sure the code has been downloaded from <https://github.com/jdicecco/UTAP>. The code we need is titled `UTAP_2023.py`. If you didn't follow along during the lecture and you still need to get the software, it's pretty simple. Make sure your current working directory is Desktop/RPi, then type `git clone https://github.com/jdicecco/UTAP.git`. You will find there is a new folder in your RPi directory called UTAP. In that folder is a Python script called `UTAP_2023.py`. Using either FileZilla or the terminal, make a copy of the script and place it in the RPi folder. Using the terminal, simply change directory to the new folder (`cd UTAP`) then type `cp UTAP_2023.py /home/pi/Desktop/RPi`, which will copy the file from the UTAP folder that you just changed into to the RPi folder. (See figure 42)

```

pi@raspberrypi:~ $ cd Desktop
pi@raspberrypi:~/Desktop $ ls
pi@raspberrypi:~/Desktop $ mkdir RPi
pi@raspberrypi:~/Desktop $ ls
RPi
pi@raspberrypi:~/Desktop $ cd RPi
pi@raspberrypi:~/Desktop/RPi $ git clone https://github.com/jdicecco/UTAP.git
Cloning into 'UTAP'...
remote: Enumerating objects: 140, done.
remote: Counting objects: 100% (61/61), done.
remote: Compressing objects: 100% (38/38), done.
remote: Total 140 (delta 28), reused 53 (delta 23), pack-reused 79
Receiving objects: 100% (140/140), 41.80 MiB | 1.34 MiB/s, done.
Resolving deltas: 100% (66/66), done.
pi@raspberrypi:~/Desktop/RPi $ ls
UTAP
pi@raspberrypi:~/Desktop/RPi $ cd UTAP
pi@raspberrypi:~/Desktop/RPi/UTAP $ ls
9dof_calibration.py      README.md          UTAP_2022.py
GERBER_DAUGHTER_V1_1.zip sensor_GUI.py    UTAP_2022_RPi.pdf
GERBER_SENSOR_V1_1.zip   UTAP2022_DAUGHTER_v1.1.brd  UTAP2022_SENSOR_v1.1.brd
launcher.sh              UTAP2022_DAUGHTER_v1.1.sch  UTAP2022_SENSOR_v1.1.sch
LICENSE                 UTAP_2022_EngReport_template.doc
pi@raspberrypi:~/Desktop/RPi/UTAP $

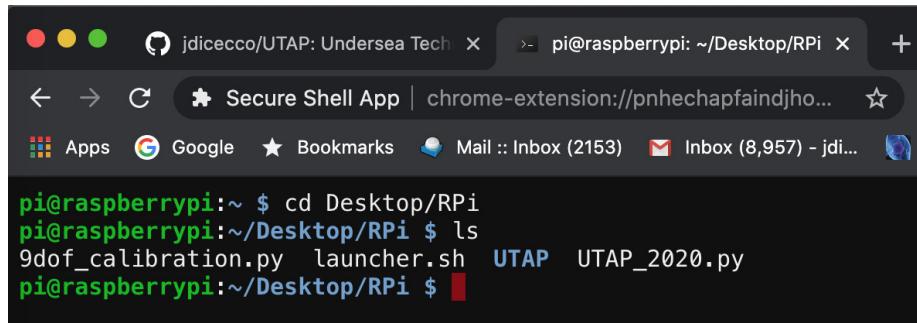
```

Figure 42: Terminal commands to get code from the Git repository.

As previously indicated, the primary interface between your laptop PC and the RPi will be a command line SSH connection. First, navigate to the folder that is on the RPi desktop. Once you're logged into the RPi, enter `cd Desktop/RPi`(figure 43). This folder contains the base code that needs to be modified. To verify the files and other folders in the RPi folder, simply type `ls`. This will list the files (white) and folders (blue) as well as executable files (green) in the folder. The `ls` command works on all folders. Appendix B lists a handful of helpful commands for navigating a command line interface in Linux.

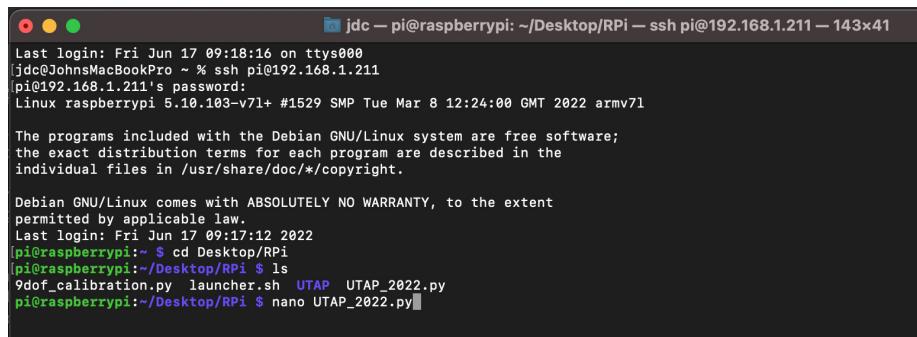
You should see a file titled `UTAP_2023.py`. This is the file that contains the base software for your RPi to control the vehicle. To modify it, you'll need to open the file for editing. The easiest way to

do this is to open it right in the command line window. Using the editor nano, simply type nano UTAP_2023.py (figure 44) and you'll see the text appear in the window. **Remember, the mouse will not work for navigation!** You'll need to use the keyboard navigation (arrows, page up/down, home, space, etc.) to move from line to line - you won't be able to mouse-click to a new location.



```
pi@raspberrypi:~ $ cd Desktop/RPi
pi@raspberrypi:~/Desktop/RPi $ ls
9dof_calibration.py launcher.sh UTAP UTAP_2020.py
pi@raspberrypi:~/Desktop/RPi $
```

Figure 43: Change the directory to the Desktop of the RPi.



```
jdc — pi@raspberrypi: ~/Desktop/RPi — ssh pi@192.168.1.211 — 143x41
Last login: Fri Jun 17 09:18:16 on ttys000
[jdc@JohnsMacBookPro ~ % ssh pi@192.168.1.211
(pi@192.168.1.211's password:
Linux raspberrypi 5.10.103-v7l+ #1529 SMP Tue Mar 8 12:24:00 GMT 2022 armv7l

The programs included with the Debian GNU/Linux system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Fri Jun 17 09:17:12 2022
(pi@raspberrypi:~ $ cd Desktop/RPi
(pi@raspberrypi:~/Desktop/RPi $ ls
9dof_calibration.py launcher.sh UTAP UTAP_2022.py
(pi@raspberrypi:~/Desktop/RPi $ nano UTAP_2022.py]
```

Figure 44: Use the "nano" text editor to modify your code.

Using only the keyboard to navigate through a file does take some getting used to. For the slightly more advanced student, the UTAP_2023.py file can be transferred to your laptop where you can use a word processing application (such as Notepad++) to modify the code. Then, when you are finished modifying the code, simply transfer it from the laptop back to the RPi. There are a number of ways this can be accomplished. One of the more popular methods is to use a program called FileZilla (engineers don't get out much).

FileZilla is a file sharing application that is used to transfer files between two computers that are connected through a SSH. Of course there are other types of connections besides SSH through which FileZilla can send files, but since we are already using SSH, that's what we'll use.

Open the application FileZilla (it is already installed on the laptop). A window will appear like figure 46. You'll need to fill out the fields indicated by the red arrows and click Quickconnect. The Local

The screenshot shows a terminal window titled "Secure Shell App" with the command "pi@raspberrypi: ~/Desktop/RPi". The file "UTAP_2020.py" is open in the nano text editor. The code in the file is as follows:

```
GNU nano 3.2          UTAP_2020.py

import threading
import time
import math
import board
import busio

#We tried several IMU sensors - may go back to this one
#import adafruit_lsm303dlh_mag
#import adafruit_lsm303_accel
#import adafruit_l3gd20
#import adafruit_fxos8700
#import adafruit_fxas21002c

#OLED screen
import adafruit_ssd1306

#PWM Board
import adafruit_pca9685

#Temp, Humidity, Pressure Sensor
import adafruit_bme280

#For OLED screen support
from PIL import Image, ImageDraw, ImageFont

#Error handling
import subprocess

#For access to operating system and array types
#Joystick support
import os, sys, struct, array

#Input output control
```

At the bottom of the terminal window, there is a menu of keyboard shortcuts:

- ^G Get Help
- ^O Write Out
- ^W Where Is
- ^K Cut Text
- ^J Justify
- ^C Cur Pos
- M-U Undo
- ^X Exit
- ^R Read File
- ^Y Replace
- ^U Uncut Text
- ^T To Spell
- ^L Go To Line
- M-E Redo

Figure 45: You can type and modify your code from here. Follow the commands at the bottom of the screen to exit and save your modified code.

site: (yellow highlight) is the current directory on your laptop where files will be transferred to/from. By default, you'll see the entire computer directory in a directory tree so you can pick where you'd like to transfer files to/from (figure 47). You could create a folder on your desktop, for instance, with your team name and select that as the Local site:. On the other side, you'll see Remote site: (also yellow highlight). This is your Raspberry Pi. Navigate to Desktop/RPi and you'll see all the files listed in the folder.

Simply click on the UTAP_2023.py file and drag it over to the folder displayed in the Local site: window. Now that file is on your laptop and you can edit it with an application like Notepad, or even better, Idle, which is a Python-specific editor. (This should already be on your laptop) (figure 48). Because Python is unforgiving when it comes to indent spacing, it's probably best to use an editor that preserves indent spacing. Also, note the color change of certain words/commands (figure 49). These are keywords and the editor is telling you they have specific functions associated with the words.

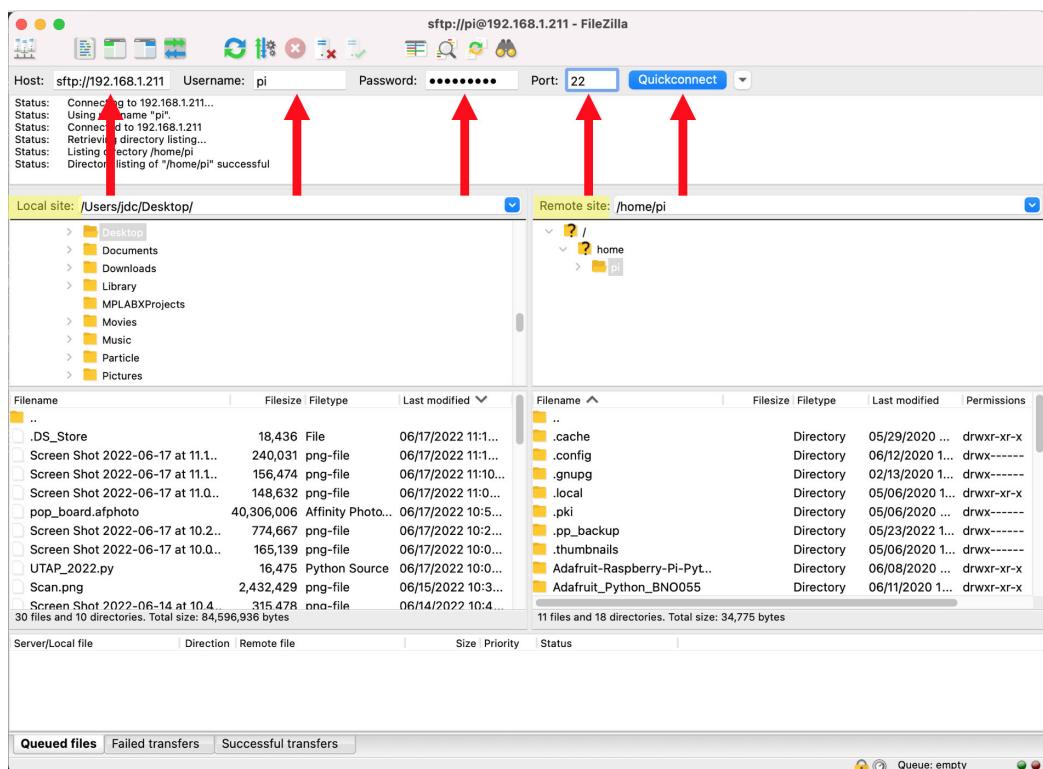


Figure 46: Filezilla.

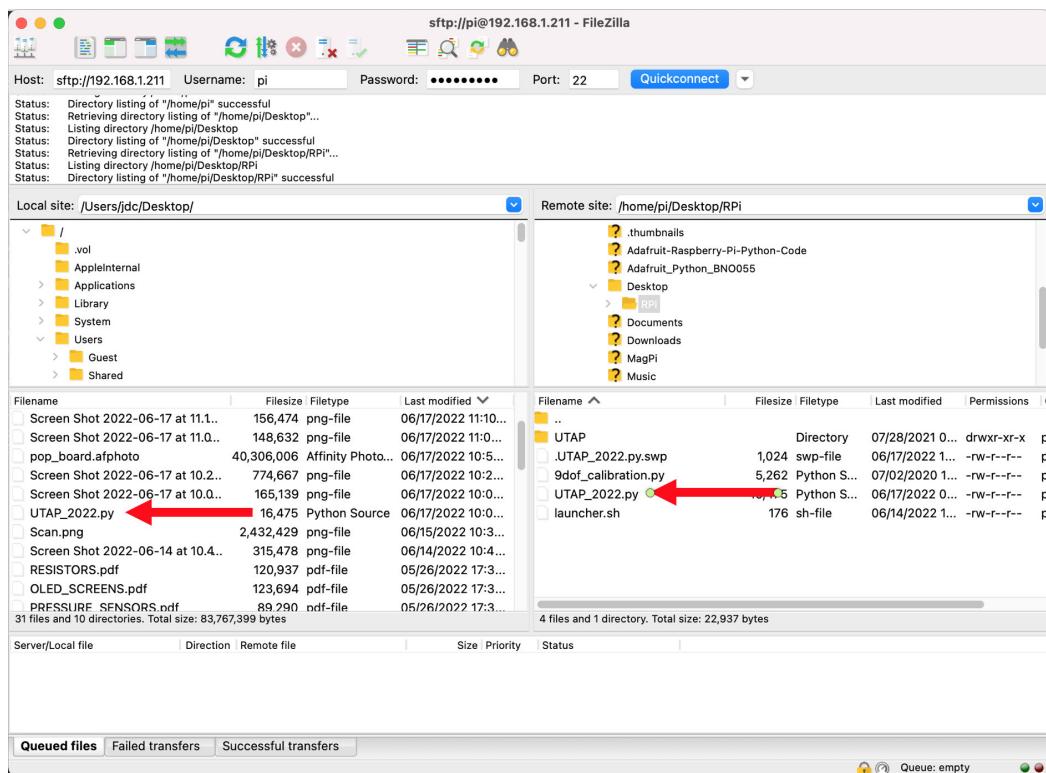


Figure 47: The navigation tree structure of Filezilla.

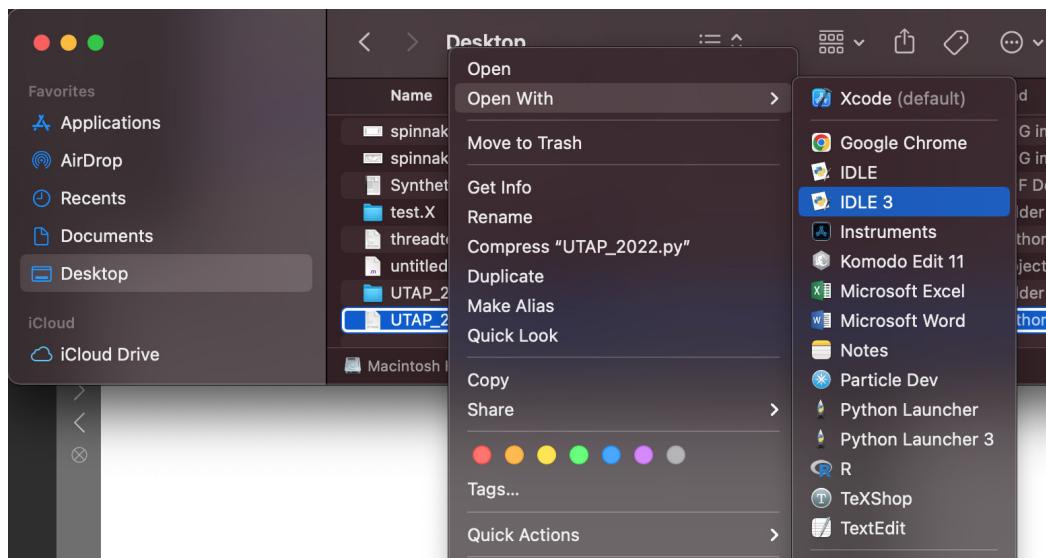
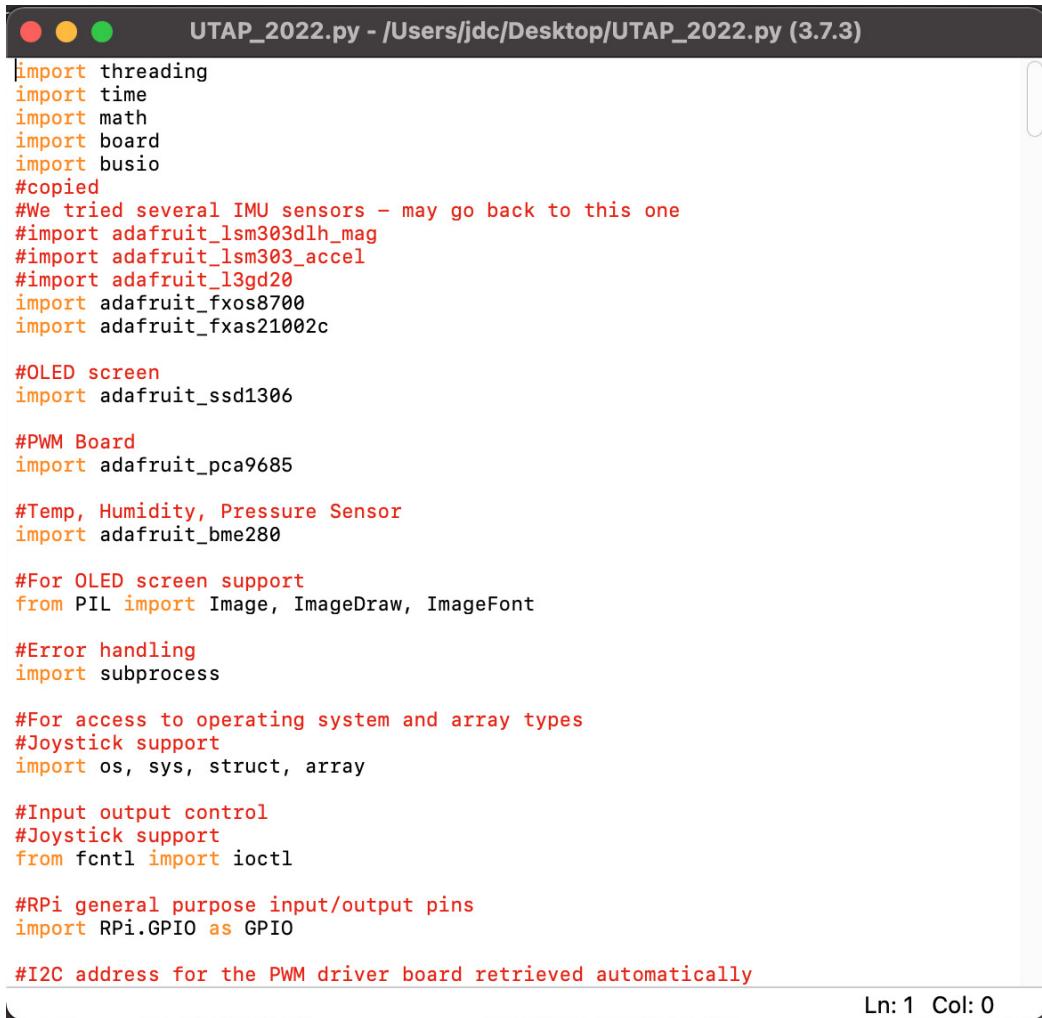


Figure 48: Edit with Idle should appear in the task window.



The screenshot shows a window titled "UTAP_2022.py - /Users/jdc/Desktop/UTAP_2022.py (3.7.3)". The code editor displays a Python script with various imports and comments. The imports include threading, time, math, board, busio, adafruit_lsm303dlh_mag, adafruit_lsm303_accel, adafruit_l3gd20, adafruit_fxos8700, adafruit_fxsas21002c, adafruit_ssd1306, adafruit_pca9685, adafruit_bme280, PIL, subprocess, os, sys, struct, array, fcntl, and RPi.GPIO. The code also includes comments for IMU sensors, OLED screen support, PWM Board, and error handling.

```
import threading
import time
import math
import board
import busio
#copied
#We tried several IMU sensors - may go back to this one
#import adafruit_lsm303dlh_mag
#import adafruit_lsm303_accel
#import adafruit_l3gd20
#import adafruit_fxos8700
#import adafruit_fxsas21002c

#OLED screen
import adafruit_ssd1306

#PWM Board
import adafruit_pca9685

#Temp, Humidity, Pressure Sensor
import adafruit_bme280

#For OLED screen support
from PIL import Image, ImageDraw, ImageFont

#Error handling
import subprocess

#For access to operating system and array types
#Joystick support
import os, sys, struct, array

#Input output control
#Joystick support
from fcntl import ioctl

#RPi general purpose input/output pins
import RPi.GPIO as GPIO

#I2C address for the PWM driver board retrieved automatically
```

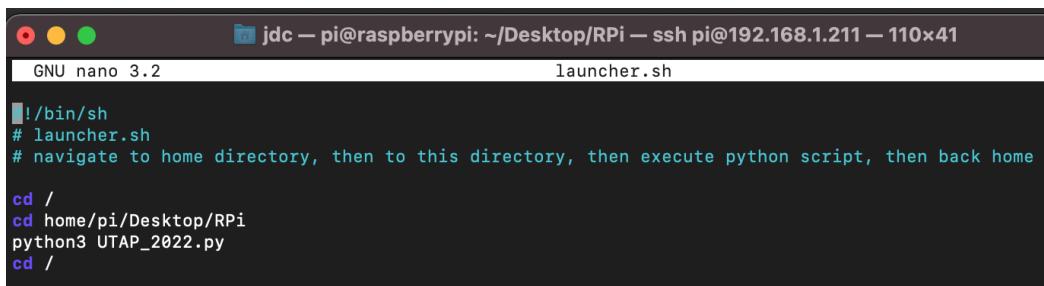
Ln: 1 Col: 0

Figure 49: The code as it appears in the Idle editor.

16.1 Running Code at Boot-Up

In order to make sure the software will run when the RPi is initially powered (without being connected to a computer), we need to make a shell script that will execute the code at boot time. This is necessary because it may not always be feasible to have a computer connected to it. In fact, when we are going to the base, we will NOT be able to bring computers. The shell script is placed in a root folder of the RPi and points to the UTAP Python code on boot. To make sure we are not running two instances of the program, we will only do one or the other. That is, we will either be modifying code during development and running it for testing purposes or we will run the program after development to execute the final code.

The shell script (like an executable file) is already in your RPi folder on the RPi's desktop. A line in the file `launcher.sh`⁵ that points to the `UTAP_2023.py` program has been commented out with the `#` character. Simply remove the `#` from the line (figure 50) and your program will execute at boot time. There will be no need to run the command `python UTAP_2023.py` from the command line.



```
GNU nano 3.2
#!/bin/sh
# launcher.sh
# navigate to home directory, then to this directory, then execute python script, then back home
cd /
cd home/pi/Desktop/RPi
python3 UTAP_2022.py
cd /
```

Figure 50: The launcher script.

17 Thruster Control

Recall from the SeaPerch you previously constructed, the color of the twisted pair of wires from the CAT-5 Ethernet cable was mapped to a specific motor, i.e. the blue twisted pair provided power to the left thruster, the green twisted pair provided power to the right thruster and the orange twisted pair provided power to the up/down thruster. The brown twisted pair was not used in the original SeaPerch design. We will now be using the brown wire but we'll also be using an additional Ethernet cable which will provide power for an additional four thrusters. This is where things get complicated, since the Ethernet cables will appear to be identical. Referring to figure 24, notice that the Ethernet jacks were labeled as RJ1 and RJ2 to help you keep track of which motors are being controlled by the software. So, OR1 in the software controls the thruster connected to the orange twisted pair belonging to the Ethernet cable plugged into RJ1. You might want to label your Ethernet cables so you'll know which motors are being controlled by the software.

⁵Incidentally, the .sh extension identifies this file as a shell script.

A The Code

The code is maintained on GitHub at <https://github.com/jdicecco/UTAP>

References

- [1] Raspberry Pi Foundation <https://www.raspberrypi.org/>
- [2] Bohm, H. and Jensen, V. *Build Your Own Underwater Robot and Other Wet Projects*. Westcoast Words; 6th Rep edition (January 1997).
- [3] Adafruit® Online documentation <https://www.adafruit.com>
- [4] SparkFun® Online documentation <https://www.sparkfun.com>
- [5] Pololu® Online documentation <https://www.pololu.com/product/2961>
- [6] <https://github.com/>