Task 1:

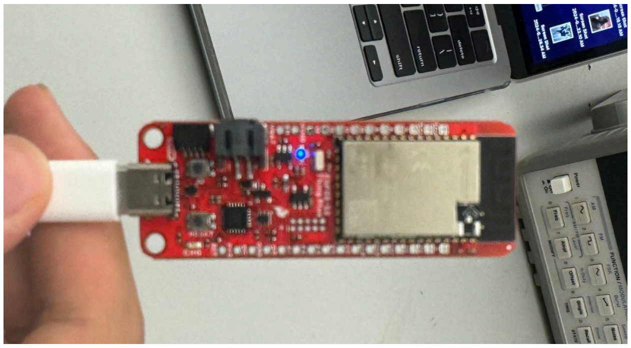

Figure 1: Working microcontroller with LED on

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Scaled. Acc (mg) [  00037.60, -00020.02,  01022.95 ], Gyr (DPS) [  00002.96, -00000.60, -00001.27 ], Mag (uT) [ -00033.15,  00028.50,  00014.85 ], Tmp (C) [  00026.74 ]
Scaled. Acc (mg) [  00025.88, -00013.18,  01035.16 ], Gyr (DPS) [  00000.56,  00001.60,  00000.66 ], Mag (uT) [ -00031.95,  00029.70,  00015.30 ], Tmp (C) [  00026.98 ]
Scaled. Acc (mg) [  00022.95, -00025.88,  01021.97 ], Gyr (DPS) [ -00000.58,  00002.25,  00000.23 ], Mag (uT) [ -00032.25,  00028.20,  00015.00 ], Tmp (C) [  00026.78 ]
Scaled. Acc (mg) [  00030.27, -00025.39,  01020.02 ], Gyr (DPS) [  00002.61,  00000.50, -00002.98 ], Mag (uT) [ -00032.10,  00029.55,  00014.10 ], Tmp (C) [  00026.98 ]
Scaled. Acc (mg) [  00031.25, -00024.90,  01023.44 ], Gyr (DPS) [  00001.03,  00002.42,  00002.27 ], Mag (uT) [ -00032.70,  00028.95,  00015.00 ], Tmp (C) [  00026.50 ]
Scaled. Acc (mg) [  00031.25, -00002.93,  01036.13 ], Gyr (DPS) [  00000.99,  00000.79, -00000.64 ], Mag (uT) [ -00033.00,  00028.65,  00016.80 ], Tmp (C) [  00026.74 ]
Scaled. Acc (mg) [  00034.18, -00011.72,  01032.71 ], Gyr (DPS) [ -00000.38, -00001.73,  00000.14 ], Mag (uT) [ -00032.10,  00028.80,  00015.60 ], Tmp (C) [  00026.83 ]
Scaled. Acc (mg) [  00030.76, -00025.39,  01023.44 ], Gyr (DPS) [ -00000.79,  00003.39,  00001.08 ], Mag (uT) [ -00031.65,  00030.15,  00015.00 ], Tmp (C) [  00026.59 ]
Scaled. Acc (mg) [  00029.30, -00010.74,  01040.53 ], Gyr (DPS) [  00000.98,  00001.06,  00001.83 ], Mag (uT) [ -00033.30,  00029.40,  00015.00 ], Tmp (C) [  00026.98 ]
Scaled. Acc (mg) [  00035.64, -00025.88,  01021.48 ], Gyr (DPS) [  00002.89, -00000.72,  00000.74 ], Mag (uT) [ -00033.15,  00029.25,  00015.60 ], Tmp (C) [  00026.78 ]
Scaled. Acc (mg) [  00028.81, -00030.27,  01026.86 ], Gyr (DPS) [  00000.70,  00000.37,  00000.53 ], Mag (uT) [ -00033.00,  00028.95,  00015.30 ], Tmp (C) [  00026.74 ]
Scaled. Acc (mg) [  00035.64, -00017.58,  01030.27 ], Gyr (DPS) [  00000.44,  00001.11, -00000.13 ], Mag (uT) [ -00032.85,  00028.50,  00014.55 ], Tmp (C) [  00026.93 ]
Scaled. Acc (mg) [  00025.88, -00011.72,  01026.86 ], Gyr (DPS) [ -00000.68,  00000.69,  00000.32 ], Mag (uT) [ -00032.55,  00029.55,  00014.85 ], Tmp (C) [  00026.93 ]
Scaled. Acc (mg) [  00035.16, -00004.88,  01016.60 ], Gyr (DPS) [  00001.94,  00001.19,  00000.13 ], Mag (uT) [ -00032.55,  00028.50,  00015.90 ], Tmp (C) [  00026.93 ]
Scaled. Acc (mg) [  00044.43, -00008.30,  01028.81 ], Gyr (DPS) [  00001.71,  00000.03, -00001.47 ], Mag (uT) [ -00033.75,  00027.90,  00015.30 ], Tmp (C) [  00026.83 ]
Scaled. Acc (mg) [  00025.39, -00014.65,  01025.39 ], Gyr (DPS) [ -00000.19, -00000.43,  00001.11 ], Mag (uT) [ -00031.35,  00028.50,  00015.90 ], Tmp (C) [  00026.74 ]
Scaled. Acc (mg) [  00020.02, -00006.35,  01030.76 ], Gyr (DPS) [  00000.02, -00000.18, -00001.07 ], Mag (uT) [ -00031.80,  00029.25,  00015.15 ], Tmp (C) [  00026.83 ]
Scaled. Acc (mg) [  00030.27, -00024.90,  01030.27 ], Gyr (DPS) [  00001.31,  00002.01, -00001.19 ], Mag (uT) [ -00031.35,  00029.25,  00015.90 ], Tmp (C) [  00026.74 ]
Scaled. Acc (mg) [  00030.27, -00021.00,  01025.88 ], Gyr (DPS) [  00001.76,  00002.38,  00001.36 ], Mag (uT) [ -00032.25,  00029.40,  00015.30 ], Tmp (C) [  00026.78 ]
Scaled. Acc (mg) [  00033.69, -00008.30,  01029.30 ], Gyr (DPS) [  00000.07,  00001.39,  00000.63 ], Mag (uT) [ -00031.95,  00027.60,  00016.05 ], Tmp (C) [  00026.83 ]
Scaled. Acc (mg) [  00028.81, -00022.46,  01017.09 ], Gyr (DPS) [  00001.02,  00000.23,  00001.02 ], Mag (uT) [ -00032.10,  00029.25,  00015.15 ], Tmp (C) [  00026.59 ]
Scaled. Acc (mg) [  00031.74, -00009.77,  01022.46 ], Gyr (DPS) [  00000.32, -00001.44, -00000.26 ], Mag (uT) [ -00032.55,  00029.55,  00016.95 ], Tmp (C) [  00026.74 ]
Scaled. Acc (mg) [  00027.34, -00014.16,  01034.67 ], Gyr (DPS) [  00002.31, -00000.87, -00000.41 ], Mag (uT) [ -00032.85,  00027.75,  00015.60 ], Tmp (C) [  00026.83 ]
Scaled. Acc (mg) [  00036.62, -00032.23,  01032.71 ], Gyr (DPS) [  00001.34, -00000.47, -00000.03 ], Mag (uT) [ -00033.30,  00028.65,  00016.80 ], Tmp (C) [  00026.74 ]
Scaled. Acc (mg) [  00035.16, -00005.37,  01033.20 ], Gyr (DPS) [ -00000.62,  00000.88,  00000.84 ], Mag (uT) [ -00031.95,  00028.95,  00015.30 ], Tmp (C) [  00026.83 ]
Scaled. Acc (mg) [  00033.20, -00012.70,  01032.71 ], Gyr (DPS) [  00001.33,  00004.74,  00001.53 ], Mag (uT) [ -00032.70,  00030.45,  00015.75 ], Tmp (C) [  00026.93 ]
Scaled. Acc (mg) [  00025.39, -00003.42,  01022.95 ], Gyr (DPS) [ -00001.40, -00000.90, -00001.53 ], Mag (uT) [ -00032.10,  00029.25,  00015.90 ], Tmp (C) [  00026.93 ]
Scaled. Acc (mg) [  00030.76, -00015.63,  01025.39 ], Gyr (DPS) [  00000.21, -00000.08,  00000.26 ], Mag (uT) [ -00031.95,  00028.20,  00014.70 ], Tmp (C) [  00026.98 ]
Scaled. Acc (mg) [  00031.74, -00014.65,  01031.25 ], Gyr (DPS) [ -00000.08,  00003.52, -00001.48 ], Mag (uT) [ -00032.70,  00028.20,  00016.80 ], Tmp (C) [  00026.93 ]
Scaled. Acc (mg) [  00033.20, -00022.46,  01024.41 ], Gyr (DPS) [ -00000.64, -00002.11,  00000.11 ], Mag (uT) [ -00034.05,  00028.95,  00015.30 ], Tmp (C) [  00026.93 ]
Scaled. Acc (mg) [  00041.50, -00004.39,  01028.32 ], Gyr (DPS) [  00002.70, -00001.31, -00001.82 ], Mag (uT) [ -00032.70,  00029.70,  00015.30 ], Tmp (C) [  00026.50 ]
Scaled. Acc (mg) [  00034.67, -00013.18,  01026.86 ], Gyr (DPS) [  00002.21, -00000.02,  00004.51 ], Mag (uT) [ -00032.10,  00028.05,  00014.10 ], Tmp (C) [  00027.12 ]
Scaled. Acc (mg) [  00038.09, -00019.53,  01035.16 ], Gyr (DPS) [ -00001.01,  00002.37, -00000.37 ], Mag (uT) [ -00032.85,  00028.80,  00015.15 ], Tmp (C) [  00026.78 ]
Scaled. Acc (mg) [  00033.69, -00020.02,  01018.07 ], Gyr (DPS) [ -00000.15,  00002.93,  00001.65 ], Mag (uT) [ -00032.55,  00029.25,  00016.20 ], Tmp (C) [  00026.74 ]
Scaled. Acc (mg) [  00041.02, -00012.70,  01033.69 ], Gyr (DPS) [ -00000.74, -00000.47,  00000.41 ], Mag (uT) [ -00032.55,  00028.80,  00015.60 ], Tmp (C) [  00026.78 ]
Scaled. Acc (mg) [  00032.23, -00018.07,  01031.25 ], Gyr (DPS) [  00000.60,  00000.47,  00000.73 ], Mag (uT) [ -00032.25,  00028.95,  00015.30 ], Tmp (C) [  00026.78 ]
Scaled. Acc (mg) [  00025.88, -00015.63,  01035.64 ], Gyr (DPS) [  00000.32,  00001.05,  00000.24 ], Mag (uT) [ -00032.85,  00028.50,  00016.20 ], Tmp (C) [  00026.74 ]
Scaled. Acc (mg) [  00023.93, -00018.55,  01034.67 ], Gyr (DPS) [ -00000.55, -00000.61, -00000.11 ], Mag (uT) [ -00031.05,  00027.75,  00015.90 ], Tmp (C) [  00026.78 ]
Scaled. Acc (mg) [  00026.86, -00020.51,  01023.93 ], Gyr (DPS) [  00000.50,  00001.60, -00000.98 ], Mag (uT) [ -00031.80,  00028.50,  00014.10 ], Tmp (C) [  00026.74 ]
Scaled. Acc (mg) [  00038.57, -00025.88,  01029.79 ], Gyr (DPS) [ -00000.37, -00001.21, -00000.50 ], Mag (uT) [ -00032.85,  00028.80,  00015.15 ], Tmp (C) [  00026.93 ]
Scaled. Acc (mg) [  00024.41, -00018.07,  01031.25 ], Gyr (DPS) [  00001.71, -00000.40,  00001.44 ], Mag (uT) [ -00031.80,  00028.50,  00015.15 ], Tmp (C) [  00026.98 ]
Scaled. Acc (mg) [  00029.79, -00027.34,  01012.21 ], Gyr (DPS) [ -00000.66,  00001.48,  00002.09 ], Mag (uT) [ -00032.25,  00028.20,  00013.95 ], Tmp (C) [  00026.98 ]
Scaled. Acc (mg) [  00021.48, -00002.44,  01029.30 ], Gyr (DPS) [ -00000.28, -00000.40, -00000.08 ], Mag (uT) [ -00032.55,  00029.55,  00015.15 ], Tmp (C) [  00026.83 ]
Scaled. Acc (mg) [  00024.90, -00012.21,  01022.95 ], Gyr (DPS) [ -00000.12,  00001.18,  00003.31 ], Mag (uT) [ -00032.10,  00027.75,  00014.55 ], Tmp (C) [  00026.93 ]
Scaled. Acc (mg) [  00025.88, -00010.74,  01023.93 ], Gyr (DPS) [ -00000.17, -00000.81, -00001.24 ], Mag (uT) [ -00033.75,  00029.40,  00015.75 ], Tmp (C) [  00026.93 ]
Scaled. Acc (mg) [  00026.37, -00018.55,  01026.37 ], Gyr (DPS) [  00000.07,  00002.90, -00000.69 ], Mag (uT) [ -00032.85,  00029.25,  00015.60 ], Tmp (C) [  00026.83 ]
Scaled. Acc (mg) [  00033.20, -00020.02,  01031.74 ], Gyr (DPS) [ -00000.10,  00000.11, -00003.63 ], Mag (uT) [ -00032.55,  00029.25,  00015.15 ], Tmp (C) [  00026.74 ]
```

Figure 2: Serial monitor with IMU printouts

Task 2:

```
.....
WiFi connected!
IP address: 172.20.10.2
Press button 0 to connect to example.com
```

Figure 3: Serial monitor showing WiFi connections

Task 3:

```
(yourenvname) (base) eugenemin@s-169-232-126-77 Lab_2 % python subscriber.py
Connection returned result: 0
Received message: "b'0.5278317030578583'" on topic "lol123" with QoS 1
Received message: "b'0.2710812488581783'" on topic "lol123" with QoS 1
Received message: "b'0.1856950377618367'" on topic "lol123" with QoS 1
Received message: "b'0.18629437817110994'" on topic "lol123" with QoS 1
Received message: "b'0.1190651860351366'" on topic "lol123" with QoS 1
Received message: "b'0.6582552894983115'" on topic "lol123" with QoS 1
Received message: "b'0.22926349176559713'" on topic "lol123" with QoS 1
Received message: "b'0.5304013463556176'" on topic "lol123" with QoS 1
Received message: "b'0.6818277095137569'" on topic "lol123" with QoS 1
Received message: "b'0.22240392694135314'" on topic "lol123" with QoS 1
Received message: "b'Hi I\xe2\x80\x99m ESP32 ^^'" on topic "lol123" with QoS 0
```

Figure 4: IMU messages received from microcontroller on computer command line

Observe how much lag is present. Are there ways to reduce the lag (e.g. reducing the frequency at which messages are sent)? What if you could do processing on the IMU itself so that only a single message is sent when something is recognized? What are other ways of getting around the lag, if you have to have lag?

There was not much lag, only a few milliseconds. Lag can be reduced by reducing the frequency of sent messages or the length of the messages. In addition, we can reduce lag through the proposed method by having the IMU do processing so that messages are sent less frequently. Other ways to get around lag, if we can not get rid of it is to lower the frame rate of our client or applying waits to our computer side so that we do not expect to receive messages as quickly.

Task 4:

1. Visually explore the IMU data from the constant stream of input upon running the IMU code. Roughly determine the +x, +y, +z directions and confirm the roll, pitch, yaw (rotations about the x, y, z axes, respectively) values. Do you see the gravity acceleration when idle?

The values changed accordingly when I rotated the IMU about the roll, pitch and yaw. I do see the gravity acceleration when idle because the z-acceleration of 1020 on the serial monitor.

2. Roughly characterize what the idle IMU position looks like from the provided features. Rotate the IMU in each direction to idle in a different orientation. Do the values drift even when idle? What is a good feature to classify idle vs. non-idle? Make this classification and record the accuracy (make a confusion matrix - how many idle experiments are classified as idle/non-idle and the same for non-idle experiments?).

When idle: Scaled. Acc (mg) [00022.46, -00021.00, 01029.30], Gyr (DPS) [00001.78, 00001.73, -00001.58], Mag (uT) [00021.15, 00017.10, 00032.85]
When idle the values do drift by a significant amount and even go from positive to negative. Looking at the gyroscope is a good feature to classify idle vs. non-idle to figure out whether the IMU is moving because when idle it is close to zero. The classifier works very well with a threshold set to 20 for all directions of roll, pitch and yaw.

Ground truth -> Classification ↓	Idle	Not idle
Idle	97	3
Not idle	1	99

3. Now build a simple classifier to differentiate between two trivial actions (forward push, upward lift) and no action - and compare your model with your teammates. What kind of features did you use? Did you do it structurally (e.g. with a decision tree)? Edit either the sketch for your Arduino or your mqtt_sub.py to do these characterizations.

For upward lift, I used the z acceleration as a feature. For forward push, I used the x acceleration as a feature. No action is the default state. I didn't do it structurally, I just used two binary values.

4. Attempt to build a classifier for 3 actions (+idle): the last 2 and a circular rotation motion (a non-trivial motion). Can you use the same features as before to do this separation? Are you able to track a circular rotation motion easily using an IMU? If you are, what features did you use? What kind of action might be easier, if not?

I can use the same features for the last two and use the gyroscope to detect the circular rotation motion. Just a circular motion is hard to detect because it detected an upward lift as I brought the IMU back into idle state. An easier action could be more linear motions like used in part 3.