1. (40 points) Count Flapula[1]

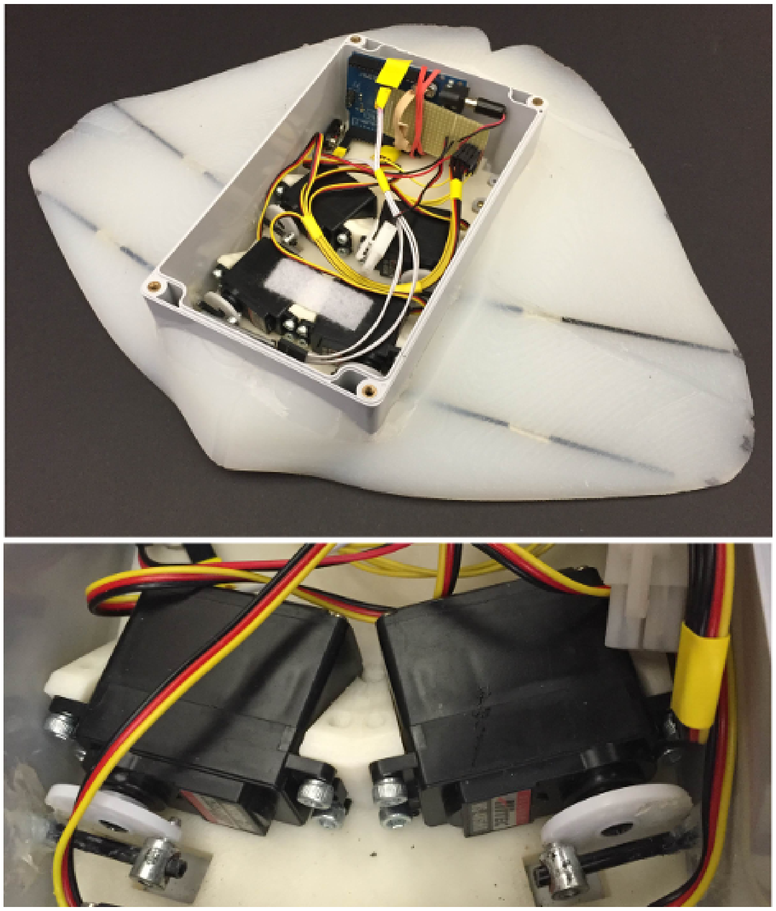

Figure 1: Count Flapula stingray-inspired robot. Top panel: The Count in all its glory, less the waterproof lid to show the actuation mechanism consisting of 4 motors that rotate carbon fiber rods. Bottom panel: Close up of the 2 rear motors showing electrical wiring. Battery power is connected via red and black wires.

Meet Count Flapula, the stingray-inspired underwater robot! This robot was designed by a student group during the winter 2015 offering of the Bioinspired Design course[2]. Full credit for the design goes to Lincoln Neely, Jack Gaiennie, and Nick Noble (2015 alums). They presented their original robot at an international conference[3] They also needed to apply a bit of their Circuits knowledge along the way!

Count Flapula's fin flaps are actuated via four total motors, two on each side. Check out Figure 1. The top panel shows the actuation mechanism. Each of 4 motors rotates a carbon fiber rod embedded in the fin made of cured silicone. A Nickel Metal Hydride (NiMH) battery pack was used to power the power-hungry motors (not shown for clarity). An Arduino Uno

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[1] Recommended sound track *Song of the Count* by Sesame Street: `https://www.youtube.com/watch?v=ZIniljT5lJI`

[2] This isn't a shameless plug for ENGN/BIOl 267, I swear :)

[3] Neely, L., Gaiennie, J., Noble, N. and Erickson, J.C., 2016, April. Stingray-inspired robot with simply actuated intermediate motion. In Bioinspiration, Biomimetics, and Bioreplication 2016 (Vol. 9797, pp. 164-177). SPIE. available here.

R3 microcontroller[4] controls the rotational amplitude and speed of the motors to make the fins of Count Flapula flap like an actual stingray. The Arduino is powered by a completely separate 9V battery.

The bottom panel of Figure 1 shows a close up of the motors' electrical wiring. Three wires run to each motor: red and black are power wires connecting to the NiMH battery pack; and the yellow wire is the control signal wire (connected to the Arduino). The Count Flapula design team chose rechargeable battery to power the motors with specfications of "6V, 1600 mAh"[5]. The real-life battery is modeled as an ideal voltage source $V_b = 6$V in series with $R_{in} = 0.32\ \Omega$. The Count Flapula design team also smartly selected a motor[6]. The current draw for a *single* motor running at full speed and powered by a 6 V battery pack was measured to be $i_{max} = 960$ mA. Importantly, the voltage drop across a motor must be 4.8 - 6V for them to function properly.

(a) Figure 2 shows the battery pack connected to a *single* motor. The battery pack's voltage $V_b = 6$V. A friendly remind the battery's internal resistance is $R_{in} = 0.32\Omega$. The motor is modeled by resistor R_1. Compute the resistance of a motor R_1. Assume the Count Flapula is running full steam ahead.

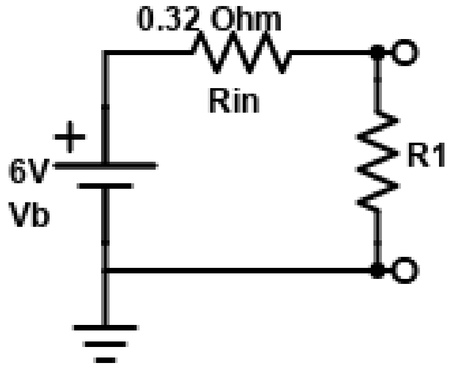

Figure 2: Count Flapula circuit model with only one motor powered by the battery.

(b) Now add 3 more motors to the circuit such that all 4 motors are properly connected to the battery pack. All 4 motors are equivalent. Each of 4 motors should be labeled with subscripts R_1, R_2, R_3, and R_4, respectively. Compute the total equivalent resistance of taking into account all 5 resistors in the circuit.

(c) Now compute the following: 1) voltage drop across the motors; 2) voltage dropped internally in the battery; 3) total amount of current flowing in the system; and 4) current flow through each of 4 motors (in comparison to a single motor running at maximum speed).[7]

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[4] They really are useful in real world projects!

[5] NiMH battery: `http://www.robotshop.com/en/6v-1600mah-rechargeable-nimh-battery.html`

[6] Hi-Tec motor: `http://www.robotshop.com/en/hitec-hs-485hb-servo-motor.html`

[7] This problem statement was updated 12.12 pm, Oct 06 2022. Props to Tyler Hellstern who pointed out the logical

(d) For how long can Count Flapula swim with the motors running at the maximum speed? Assume the NiMH battery pack starts fully charged.

(e) What is the maximum number of motors that could be properly powered by the NiMH battery. Recall that the voltage drop across the motors must be 4.8 - 6V for them to function properly. (If a motor is powered by $\leq$ 4.8 V, the digital hardware expecting 5V pulses doesn't know what to do with pulses that are too small in amplitude.)

(f) At one point during development of the robot, Count Flapula's fins weren't flapping. A quick diagnostic was to measure the voltage across each motor, which turned out to be $\approx$1.5 V. Suggest a likely scenario for how the system was wired incorrectly. Draw any circuit diagrams and show relevant calculations to support your claim.

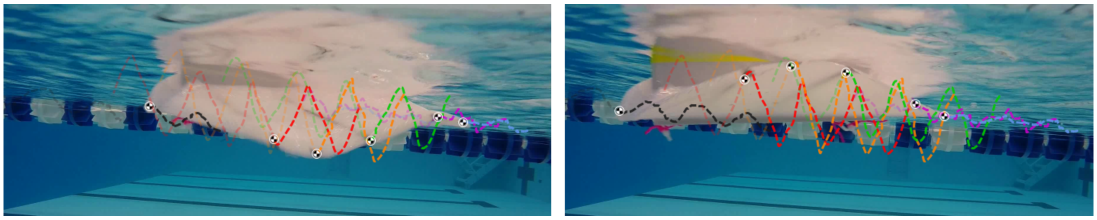

Figure 3: Count Flapula swimming in the W&L pool. The fin deformation profile is tracked over time. Left and right panels show fin at end of successive upstroke and downstroke, respectively. A maximum forward velocity of 10 cm/s flapping at 2 fin beats/sec was achieved.

2. **Resistance is Futile (5 bonus points!)**

   Imagine you need a 1kΩ and a 20 kΩ resistor for a circuit you want build. One problem: you can only find one bag of resistors in the lab, all 5kΩ. Invent and briefly describe a work-around to the seeming problem of not having the right value resistors on hand.

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inconsistency in the first incarnation of this problem statement, which has now been fixed. In fact, all 4 motors can't simultaneously draw 960 mA each, as was originally suggested in the first incarnation of the problem statement.

3. Stayin' Alive: Soil Moisture Monitor Design Problem (50 points)

Plants, like people, thrive under optimal conditions. Plants are simpler than people, they basically need sunlight and water. But in just the right amount. The aim of this problem is to design a simple soil moisture monitor. It should be able to measure the resistance of the soil and thereby infer one of three states: too wet, too dry, just right. The basic idea is to treat the soil itself a resistor; we connect to it electrically by placing two metal contacts in the soil (see Figure 4). The moisture level of the soil is inversely proportional to the resistance: more water equal less resistance and vice versa. Too wet soil has a resistance ≤ 30 kΩ. Too dry has a resistance ≥ 300 kΩ. Just right soil falls in between these limits. Your system must be able to:

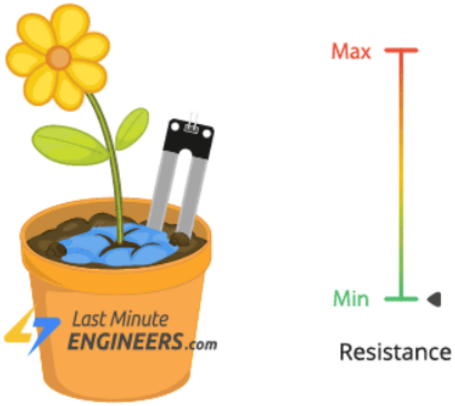


Figure 4: Soil moisture monitor probes affixed in the soil next to a pretty flower. Image credit: `https://lastminuteengineers.com/soil-moisture-sensor-arduino-tutorial/`

- Print out or plot in real-time the resistance of the soil
- Illuminate an LED indicating the soil moisture state: green for too wet; red for too dry; yellow for just right. Assume the LEDs will illuminate brightly, as desired, when 20 mA of current flowing through them.

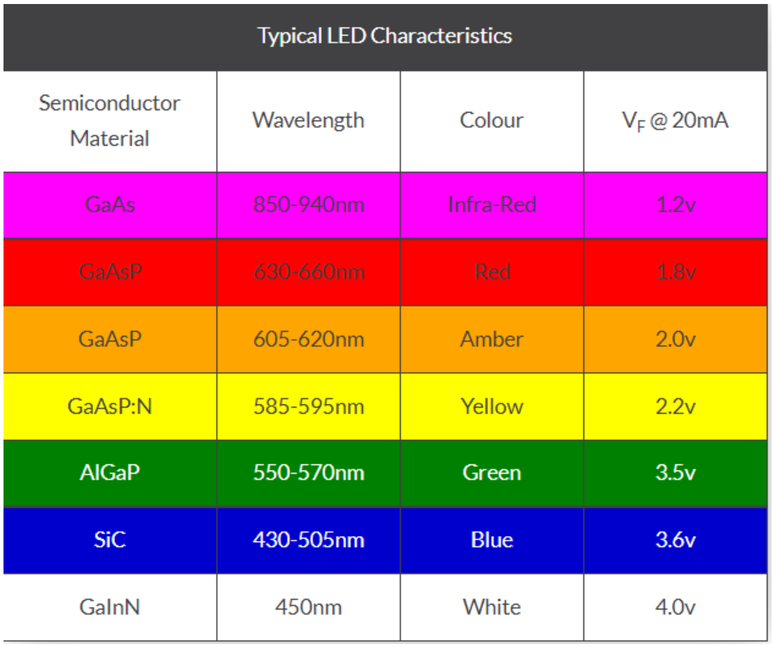
Complete the design of the soil moisture. You may find the information in Figure 5 to be helpful for the LED portion of the design . Remember the forward voltage drop is how many volts are 'eaten up' by the LED (akin to how many Newtons of force you have to apply to a sticky valve before it pops wide open to allow current to flow). A good solution should illuminate:

(a) The general working principle/idea of the circuit

(b) The design rationale, supported by calculations, where appropriate.

(c) Of course be sure to diagram the all circuitry involved.

(d) Your Arduino code. For this part, you may access any of the Arduino tutorials on the eponymous website, if you like.



Typical LED Characteristics			
Semiconductor Material	Wavelength	Colour	V_F @ 20mA
GaAs	850-940nm	Infra-Red	1.2v
GaAsP	630-660nm	Red	1.8v
GaAsP	605-620nm	Amber	2.0v
GaAsP:N	585-595nm	Yellow	2.2v
AlGaP	550-570nm	Green	3.5v
SiC	430-505nm	Blue	3.6v
GaInN	450nm	White	4.0v

Figure 5: LED characteristics Image credit: `https://www.electronics-tutorials.ws/diode/diode_8.html`