Assignment 3: Motors & Transmissions

Due 03/12/2022 at 11:59pm

In this assignment, we will be shifting toward more mechanical components. For the first half of this assignment, We will be covering theories relevant to transmission design and motors. For the second half of this assignment, we will introduce the basic peripherals that are required to control a DC motor and help you set it up for later control design.

Note: You do not need to turn in the solution for every single problem. Only submit what is marked as ***Deliverables***. *Combine all your answers into a single PDF in order, including the links to your videos. Submit the PDF to* bCourses.

1 Theory: The fundamentals

1.1 Gear ratio

Compute the gear ratio for the following system

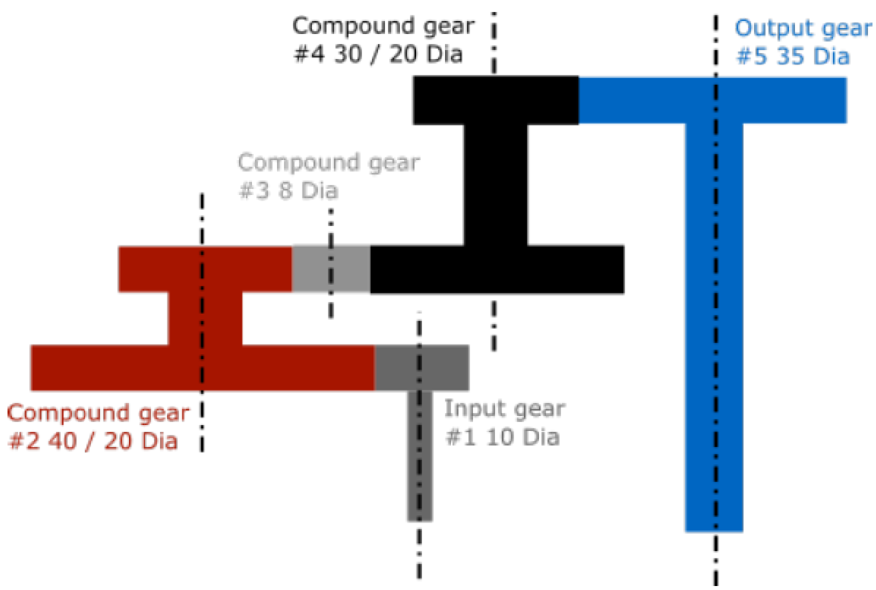

Figure 1: Cross-sectional view of a gear train, with the diameter listed in millimeters for each gear or compound gear (input / output)

Deliverables **Written:** What is the total transmission ration? For an input torque of 1 N-cm, what is the output torque? For an input speed of 10 rotations per second, what is the speed at the output?

1.2 Gear motor reaction force

The pressure angle of a gear set describes the tooth contact force line of action. As a result, we can treat tooth reaction forces as acting at the contact point between the two meshing gear pitch circles, independent of real tooth orientation. This is a consequence of using a conjugate gear-tooth shape design. In the following system, the gears have a pressure angle of 20°. The input gear has a 2cm diameter.

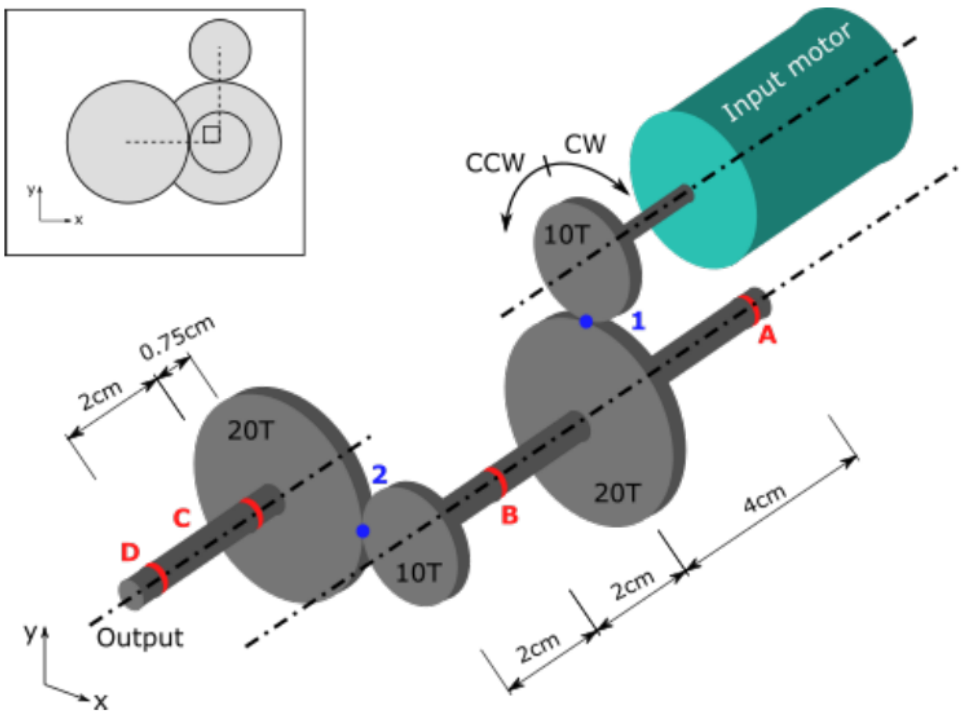

Figure 2: Gear train with teeth listed for each gear

Deliverables **Written:** For an input torque of 0.1 N-m in the clockwise (CW) direction. What are the forces acting at the teeth of the compound gear at points 1 and 2, represented in the righthanded x-y-z frame shown in the image?
Deliverables **Written:** Now take out the gear motor from the lab kit. Take a close look at the gearbox. How does the diameter of the shaft change along the gear train? Why is that?

1.3 Planetary gear

Shown below is the schematic of a planetary gearbox. The ring gear is held fixed. The input is the sun gear and the output is the planet carrier.

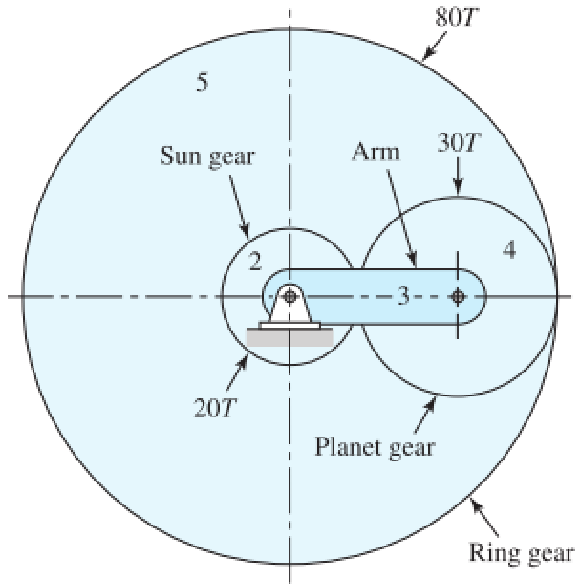

Figure 3: Switch Debounce

***Deliverables* Written:** Derive the gear ratio formula for the given condition. Then use that and compute the gear ratio for the above planetary gear.

1.4 Flexible drives

Capstan cable drives can be lightweight and highly efficient. They rely on the friction that builds up when you wrap a wire around a drum multiple times. For the system shown below, the input is the small 1cm diameter capstan. The cable is terminated and tensioned on the 8cm output. The friction coefficient between the cable and capstan is 0.7.

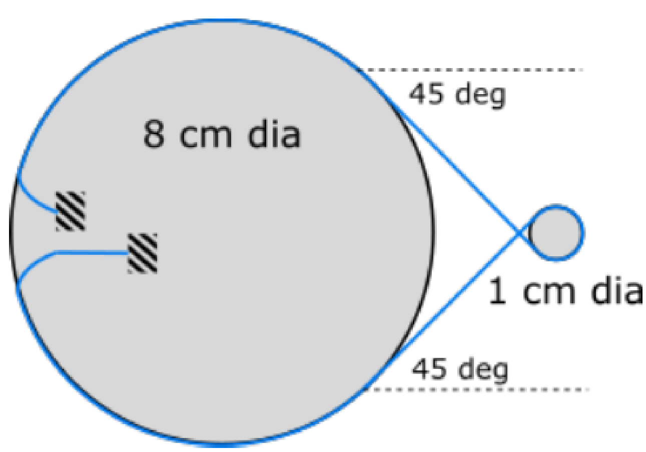

Figure 4: Capstan drive, single stage

Deliverables **Written:** Given a cable pre-tension of 25 N and that there is 0.75 wrap of the cable about the input capstan, how much torque can be transmitted to the output?

2 Practical: Running the motor

2.1 Power supply

So far we have been using the USB and the 3.3v pin from the ESP32 to supply the power. While this is sufficient for a small number of low-power sensors, we cannot use the same approach for a motor since it will require a lot more power. Find the 5V power supply in your lab kit. You will need to use the converter to connect it to the breadboard. Connect the power supply to the power rail on top of the breadboard and connect its ground to the ESP32 ground (common ground).

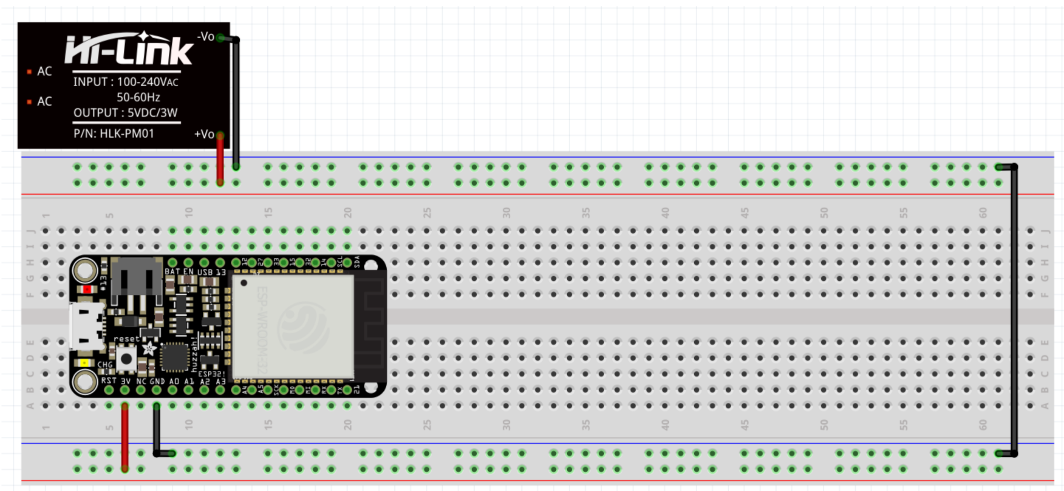

Figure 5: Power supply connection

2.2 Motor driver

We will be using the DRV8833 to drive our motor. The DRV8833 has two H-bridge drivers and can drive two brushed motors. For this class, we only need to use one of the two bridges. Below is the wiring for using the DRV8833 with a microcontroller. Read https://www.pololu.com/product/2130 before you connect the wires.

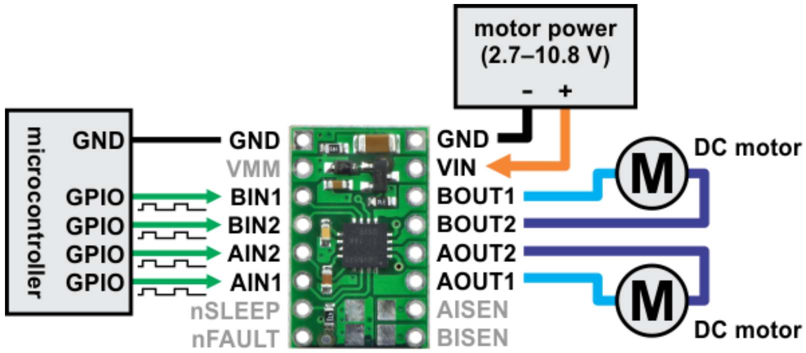

Figure 6: Minimal wiring diagram for connecting a microcontroller to a DRV8833 dual motor driver carrier.

Once you feel comfortable with the basics of the DRV8833, connect it to your ESP32 and the motor like the picture shown below. You will need

- 1 × DC gearmotor
- 1 × motor driver (DRV8833)
- 1 × motor mounting bracket
- 1 × encoder and connector (the encoder is built-in on your motor)
- 1 × wood board

Note that we are not using the other GND pin on the DRV8833. This is because we already have a common ground between the two power rails. Your motor should have 6 wires coming out, and you only have to use the M1 and M2 wires to power it. Refer to https://microkit.berkeley.edu/encoder/ if you are not sure about which ones to use. Secure your motor to the wood board provided in the kit for safety concerns.

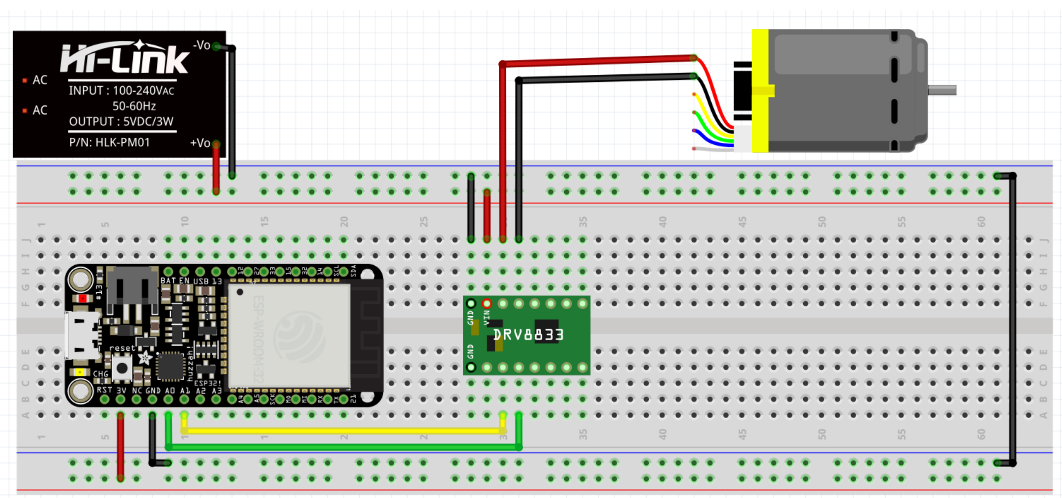

Figure 7: Using DRV8833 with the ESP32

The yellow and green wires coming out from the bottom of the DRV8833 are the signal wires. If you pull one of them to LOW and send a PWM signal to the other, the driver will output a voltage to the motor corresponding to your PWM wave. If you change the order of connection, that you pull the other wire to LOW, then the output voltage will change its direction. That being said, you can connect the yellow wire to GND and the green wire to 3.3V and you should be seeing the motor rotating at full speed. You should also see the motor changing its direction once you switch the wire connections.

Now, open **motor_driver_template.ino**. Upload the code to your ESP32 and the motor should be switching between full-speed clockwise rotation and full-speed counter-clockwise rotation. Change the code such that the output is sinusoidal. Note that since the motor direction has to change, you need to periodically switch which pin to be pulled LOW in your function.

Deliverables **Video:** Take a video of your motor rotating in a sinusoidal manner.

2.3 Encoder

In order to do closed-loop control, we will need to know the position and speed of our motor. This requires us to use the encoder. The encoder in the lab kit uses a magnetic disc and Hall effect sensors to provide 12 counts per revolution of the motor shaft. We will not discuss in detail how the counting mechanism works, but if you are interested, you can read it here: https://lastminuteengineers.com/rotary-encoder-arduino-tutorial/.

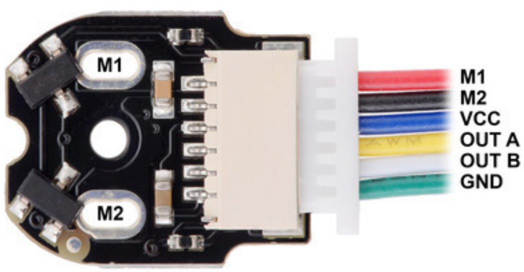

Figure 8: The encoder in your lab kit

Connect the encoder to your ESP32 like the picture shown below. Note that the order of encoder wires in the picture is different from what you have, but the colors match so use that as the reference.

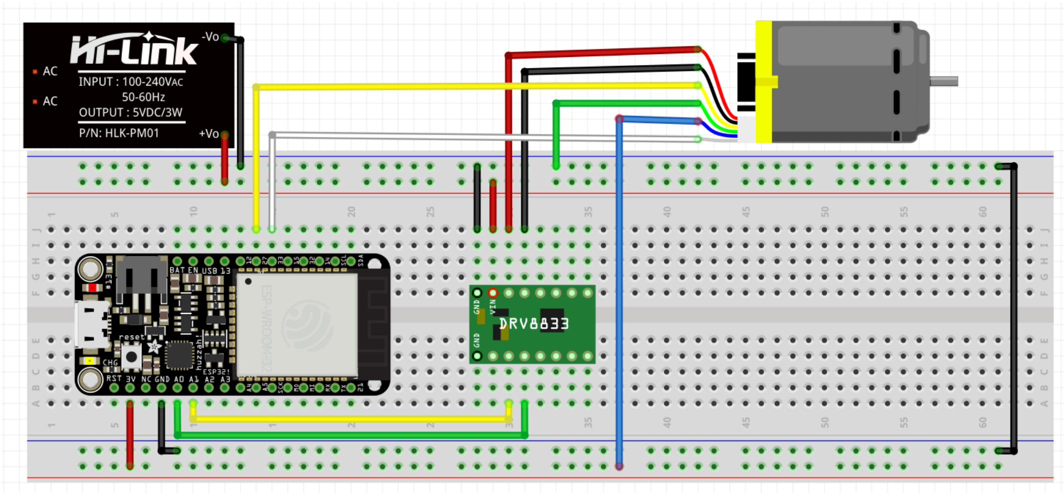

Figure 9: Connecting the encoder

We are going to use the "ESP32Encoder" library to make our lives easier. Download the latest release from https://www.arduino.cc/reference/en/libraries/esp32encoder/ and install it. Then, open **encoder_template.ino** and upload it to your ESP32. You should see the count changing by 75.81×6 if you rotate the motor output shaft by a full revolution. It is multiplied by 6 instead of 12 because the library has a lower resolution.

Note: If you are not getting any count update, open ***encoder_test.ino****. This prints out the two encoder output pin readings directly. If you do not see the value changing, and you are sure there is no bug in your wiring and software, then the low-quality encoder connector might have poor contact. Check the wires and use your screwdriver to push the wire into the clamp for better contact.*

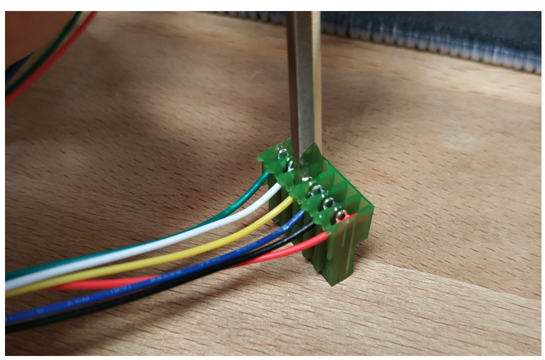

Figure 10: Encoder connector fix

2.4 Monitoring the motor with the encoder

Finally, let's combine the motor code and the encoder code and have them run together. For the motor side, use the same sinusoidal output. For the encoder side, change your code such that it not only measures the count of the motor, but also the speed of the motor (after reduced by the gearbox). You will need to discretize the measurement so make sure you have a constant sampling time, so use "millis()" or interrupt instead of "delay()". Finally, use the Serial Plotter to monitor how the motor speed changes with your sinusoidal input. Refer to https://arduinogetstarted.com/tutorials/arduino-serial-plotter for how to use the Serial Plotter if you do not know.

Deliverables **Photo:** Take a screenshot of your Serial Plotter plotting the motor speed and motor PWM input with labels.
Deliverables **Written:** Design a simple experiment that measures the efficiency of the gear motor. Describe your method briefly. Note: You do not have to carry out the experiment but you are welcome to do so and let us know what your findings are.

Helpful resources

Arduino Programming Language: https://www.arduino.cc/reference/en/
HUZZAH32 Documentation: https://learn.adafruit.com/adafruit-huzzah32-esp32-feather
HUZZAH32 Pinouts: https://learn.adafruit.com/adafruit-huzzah32-esp32-feather/pinouts
The Lab Kit: https://microkit.berkeley.edu/blank-page/
Installing Arduino Libraries: https://www.arduino.cc/en/Guide/Libraries
Arduino Serial Plotter: https://arduinogetstarted.com/tutorials/arduino-serial-plotter

Deliverables checklist

Deliverables **Written:** What is the total transmission ration? For an input torque of 1 N-cm, what is the output torque? For an input speed of 10 rotations per second, what is the speed at the output? (10%)
Deliverables **Written:** For an input torque of 0.1 N-m in the clockwise (CW) direction. What are the forces acting at the teeth of the compound gear at points 1 and 2, represented in the righthanded x-y-z frame shown in the image? (15%)
Deliverables **Written:** Now take out the gear motor from the lab kit. Take a close look at the gearbox. How does the diameter of the shaft change along the gear train? Why is that? (10%)
Deliverables **Written:** Derive the gear ratio formula for the given condition. Then use that and compute the gear ratio for the above planetary gear. (15%)
Deliverables **Written:** Given a cable pre-tension of 25 N and that there is 0.75 wrap of the cable about the input capstan, how much torque can be transmitted to the output? (10%)
Deliverables **Video:** Take a video of your motor rotating in a sinusoidal manner. (10%)
Deliverables **Photo:** Take a screenshot of your Serial Plotter plotting the motor speed and motor PWM input with labels. (10%)
Deliverables **Written:** Design a simple experiment that measures the efficiency of the gear motor. Describe your method briefly. Note: You do not have to carry out the experiment but you are welcome to do so and let us know what your findings are. (20%)

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