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Measuring Motor Resistance

Introduction

To design stable and robust PID controllers for the quadcopter, we need to first create a mathematical model of the quadcopter. Following the mathematical model representation described in Matt Rich's thesis, which is cited as a reference in the last section of this document under "References", the first step we need to go through is *system identification*. This basically means that we need to characterize our quadcopter system by finding specific parameters that affect how it behaves when it flies. These parameters include, for example, the mass of the quadcopter, its moment of inertia about different axes of rotation, the length from the center of the quadcopter to the motor hubs, etc. One important parameter for the quadcopter, which is not as straight-forward to measure, is its *motor resistance*.

The motor resistance parameter will be an average of three measured resistance values from the motor, all three of which should be about the same value. Each measured resistance value will be taken from two of the three leads of the motor. Because the resistances being measured are very small in value (less than 1 ohm), we use a Wheatstone bridge circuit to do the resistance measurements. In this document, we will explain how we accurately measure the resistances and determine the value of the motor resistance parameter.

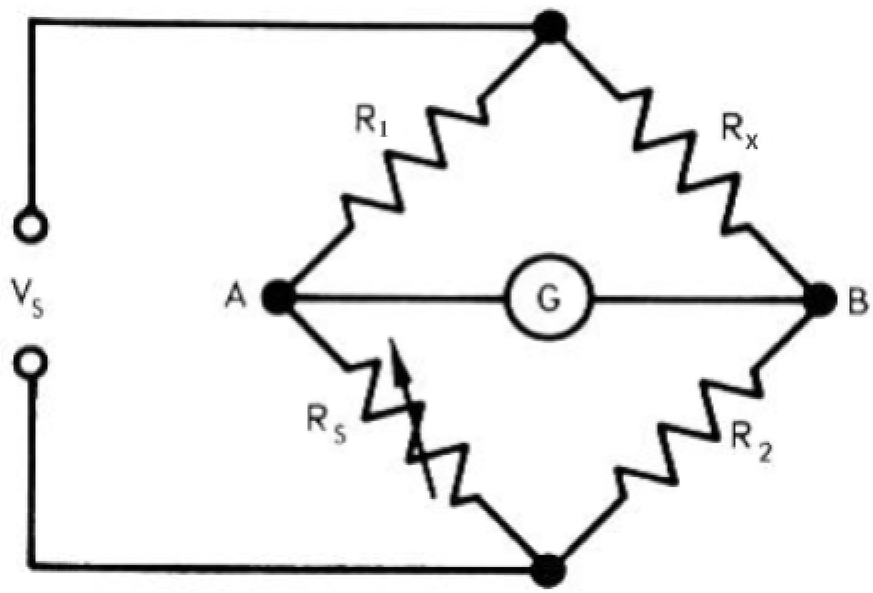
Materials

The materials needed to measure the motor resistance are the following:

- Voltmeter (or multimeter)
- DC Power Supply
- 2 known resistors (preferably one that is ~1000 ohms and another at ~10 ohms)
- Resistor box
- 6 banana-to-breadboard cables (preferably 3 red and 3 black)
- Breadboard
- Electric Tape (technically optional, but make things much easier)
- Breadboard wires, as needed

Basic Concept

A Wheatstone bridge circuit is a circuit that allows you to measure very small resistances. In general, it looks something like this:



Here, R1 and R2 are your known resistances. Technically, these resistance values won't matter, but performing the "balancing" will be easier with your resistor box, which can go to large resistance values, if you use the recommended resistances listed in the "Materials" section. The values we suggest would be about a 1000-ohm resistor (or a resistor value of a similar, medium magnitude) for R1, and a resistor of about a 10-ohm resistor (or a resistor value of similar, smaller magnitude) for R2.

Rx represents the resistor you are trying to find, in this case one of the motor resistance values, and Rs represents the variable resistance from the resistor box. We apply a voltage Vs, from the DC power supply, to the resistor circuit. And we measure the voltage between points A and B, using our voltmeter or multimeter.

The basic idea is that as we change the variable resistance, Rs, from our resistor box, the voltage between points A and B will change. And eventually, as we change Rs, there should be a point where the voltages balance out and the voltage measured between A and B equals 0. At this point, the ratio between the resistors are equal, and can be represented with the following expression:

$$R1/Rs = Rx/R2$$

Thus, knowing your Rs resistance, you can solve for the motor resistance, and you will come up with the following expression:

$$Rx = (R1 * R2)/Rs$$

Setup

Follow these steps to perform the measurements accurately and safely, without burning out the motors in case too much current is being applied.

0. (Optional step) Attach with electrical tape a different color breadboard wire to each of the three leads coming from the motor
    a. For each of the three leads, touch the metal of the breadboard wire to the metal of the lead
        - Using *different color breadboard wires* can be helpful
        - That way you can distinguish between the different leads and you don't accidentally measure the same resistance value twice
    b. Keeping the metal ends in contact, wrap this connection tightly with electrical tape, without losing the connection
    c. Note:
        - Do not have to do this step, if you don't want to
        - However, if you don't, during the entire test you'll have to manually hold the motor leads to the wires to keep it in contact with the rest of the circuit
1. Connect the resistors of your circuit
    a. Follow the connections of the resistors in the circuit diagram of the Wheatstone bridge, above
        - Important note: ***do not connect to Vs, the power supply, quite yet***
        - Need to first setup the power supply so that we protect the motors
        - This setup process for the power supply will be in step 3
    b. R1 and R2 are your known resistor values, connect these
        - Recommendation for R1 and R2 for easier "balancing":
            - Can make R1 ~1000 ohms in magnitude (medium size)
            - Can make R2 ~10 ohms in magnitude (small size)
        - Not critical, the values of R1 and R2
        - Can use any values you want, technically
        - But these recommended values will help make it easier to "balance" the voltage between A and B when adjusting the resistance of the resistor box, Rs
    c. Rx is the motor resistance, connect this from the motor leads
        - If you did step 0, simply connect the breadboard wires of any two leads into your circuit at the endpoints of Rx in the diagram
        - If you did not do step 0, just hold two of the motor leads so that they are in contact with the rest of the circuit when doing measurements
        - With each of the three resistances you measure, you will change this connection of your circuit, by switching the wires of the motor leads
        - Each time you measure a different resistance, you will change the leads so that you have a different pair of leads, and thus a different resistance to measure between the two different leads
    d. Rs is the resistance of the resistor box, connect this from its output leads

    - Connect two of your banana-to-breadboard cables to the two outputs of the resistor box
    - Take the "breadboard" side of these cables and connect it in your breadboard circuit, in the position of Rs on the circuit diagram above
2. Connect the Voltmeter to measure the voltage between points A and B of your circuit
    a. Set the multimeter to "DC V"
    b. Connect two of your banana-to-breadboard cables from the positive and negative outputs for measuring voltage
    c. Connect one lead to point A of the circuit
    d. Connect the other lead to point B of the circuit
3. Setup the DC power supply
    a. Use the 6-volt power supply (should not need to go larger than 6 volts)
    b. Current-limit the output to 0.015 A (or 15 mA)
        - This way we can protect the motors
        - So that in case the voltage is too high, we will not run too much current through the motors
    c. Set the voltage to be about 3 volts for now
        - This voltage value is not critical
            - Because we are just finding where the voltage at points A and B are the same, as we adjust the Rs (the resistance of the resistor box)
            - This depends only on the resistance ratios, and should not change with the voltage we are providing, Vs
    d. Set the output to be OFF by hitting the "Output On/Off" button
    e. Connect two of your banana-to-breadboard cables to the output of the 6-volt power supply
    f. Connect the positive and negative leads of the power supply to your circuit, as shown in the Wheatstone bridge circuit diagram, above
    g. Turn on the output of the power supply by hitting the "Output On/Off" button
    h. Check that the power supply is ***not being current-limited***
        - You will know the DC power supply is being current-limited because the current value will increase and then you will see a "CC" instead of "CV"
            - "CC" means "Constant Current", which indicates that the power supply is adjusting the voltage so that it does not go above a certain current value, thus keeping the current constant
            - "CV" means "Constant Voltage", which indicates that the power supply is trying to provide the voltage that you specified and keep it constant in value
    i. If the power supply is being current-limited: turn down the voltage until it is not being current-limited anymore (the "CC" goes away and you only see "CV")

Now you are all set-up to take your measurements! To perform the balancing of your Wheatstone bridge continue on to the next section.

Data Collection

To determine the resistance value, you first need to balance your Wheatstone bridge. To do so, adjust the resistance of your resistor box until the voltage between nodes A and B, which is currently setup to be measured by the voltmeter, is about 0 volts.

A good approach of doing this systematically is to start with all of the digits of the resistor box at 0, so that you have zero ohms. Then, incrementally increase the most significant digit until the voltage value crosses the zero volts point and changes sign. At this point, undo the last incrementation of the most significant digit, so we do not pass zero volts, and then repeat the same process but with the second most significant digit. Then, continue picking the best digit for each significant figure until you get a value that is precise enough. Certainly, you do not have to find the value to +/- 1 ohm; you can probably stop the balancing process once you have selected your hundreds digit (thus giving you an accuracy of about +/- 100 ohms) or if you really want, after selecting your tens digit (giving an accuracy of about +/- 10 ohms).

Once you have performed this balancing process of your Wheatstone bridge, the next step is to calculate the motor resistance for your current resistance orientation measurement. So, determine the resistance value that you have adjusted on your resistor box, which should balance your circuit currently. And use the formula found above in the “Basic Concept” section relating your unknown motor resistance to your two known resistances and the resistance of the resistor box.

After finding the value of your unknown motor resistance, you will repeat the same data collection process an additional two times, where you again balance the Wheatstone bridge and calculate the corresponding unknown motor resistance value. However, make sure that for the second and third time you repeat this process, you change which two pins from the motor leads you put into your circuit. This way, you will be measuring the resistance between two different leads each time, instead of accidentally remeasuring the same motor resistance.

After performing this process 3 times, one time per pair of leads to measure the resistance between, you will end up with 3 resistance values, which should be quite similar (hopefully!) . Assuming that the other three motors have approximately the same motor resistance, simply average your three resistance values. And this will indeed be your motor resistance parameter!