DC Motor Control

Small DC motors find many uses in electronic devices and are a favorite component of engineers and hobbyists. The input voltage to a motor determines how fast it rotates, but in many projects it is important to be able to measure the speed of the motor. A tachometer is an instrument that measures the rotational speed of a motor’s shaft in revolutions per minute (rpm). Tachometers are used on cars and aircraft to show the rate of rotation of the engine’s crankshaft, and can be used to assist the driver in selecting the appropriate throttle and gear settings for safe driving conditions since exceeding the maximum safe operating speed on an engine can lead to overheating and engine failure. Some tachometers use lasers to measure rotational speed; others use a small generator to produce a voltage that is roughly proportional to the rotational speed. This Project uses a Photogate to determine the speed of the motor.

PROJECT DESIGN REQUIREMENTS

In this Project, you will build a tachometer to measure the rotational speed of a DC motor. First you must build a circuit to power your motor from the Vernier Digital Control Unit (DCU). Your circuit should contain a potentiometer to allow the user to control the voltage to the motor. Then you will write a LabVIEW program to determine the rotational speed in revolutions per minute (rpm) by measuring the period of a propeller mounted to the motor shaft passing through a Vernier Photogate.

MATERIALS

- SensorDAQ, LabQuest, or LabQuest Mini
- LabVIEW computer
- USB cable
- Vernier Digital Control Unit (DCU)
- LabQuest or LabPro power supply
- Vernier Photogate
- small DC motor with propeller
- 1 kΩ potentiometer
- ring stand
- two rod clamps
- breadboard
- jumper wires
ADDITIONAL MATERIALS (SENSORDAQ ONLY)

Vernier Digital Proto Board Connector

PROJECT SETUP

Connect the DCU
1. Plug the 9-pin cable into the socket on the side of the DCU.
2. Connect a power supply to the DCU.
3. Connect the DCU to the first DIG port on the interface.
4. Connect the interface to the computer.

Construct a tachometer with a Photogate
1. Mount a propeller onto the shaft of a DC motor.
2. Support the DC motor and Photogate using a ring stand and rod clamps. The motor should be aligned such that the propeller blade blocks the light beam in the Photogate as the propeller spins. You should make sure that only one blade at a time blocks the beam.

Connect the Motor to the DCU and the Photogate to the Interface

SensorDAQ (If you are using LabQuest or LabQuest Mini, see below.)
1. Connect the potentiometer and DC motor to the D3 and GND leads on the DCU cable as shown in the diagram below.

![Wiring diagram for potentiometer-controlled motor circuit for SensorDAQ](image)

Tip: The leads on a DC motor can be connected in any order. Reversing the polarity will simply cause the motor to rotate in the opposite direction.
2. Insert a Vernier Digital Proto Board Connector into a breadboard.
3. Wire the Digital Proto Board Connector to the SensorDAQ screw terminal using jumper wires as shown in the figure below.

![Figure 2 Digital Proto Board Connector pin-out to SensorDAQ screw terminal](image)

4. Connect the Photogate to the Digital Proto Board Connector.

**LabQuest or LabQuest Mini**

1. Connect the potentiometer and DC motor to the D1 and GND leads on the DCU cable as shown in the diagram below.

![Figure 3 Wiring diagram for potentiometer-controlled motor circuit for LabQuest or LabQuest Mini](image)

**Tip:** The leads on a DC motor can be connected in any order. Swapping the order will simply cause the motor to rotate in the opposite direction.

2. Connect the Photogate to channel DIG 2 on the side of the LabQuest or LabQuest Mini.

**PROJECT BACKGROUND INFORMATION**

Motors are used to convert electrical energy to mechanical energy (in this case, rotation). Most DC motors have six basic parts: an armature or rotor, commutator, brushes, axle, field magnet, and stator. The stator is the stationary part of the motor, which includes the motor casing and two field (permanent) magnets. The rotor (which includes the axle and commutator) is an electromagnet that rotates with respect to the stator. The windings on the rotor make an electrical connection to the power source through the brushes and the commutator.
When a current flows through the rotor windings, a magnetic field is created. The rotor experiences a torque caused by the permanent magnets in the stator causing the rotor to rotate. In the diagram above, the rotor would rotate clockwise. Just before the rotor aligns with the field magnets, the commutator moves such that the brushes make contact on the opposite side and the flow of current reverses. As the current through the windings is reversed, the polarity of the magnetic field of the rotor is changed causing the rotor to continue to move and make another half turn. As the direction of current is continuously flipped at just the right moment, the rotor will turn continuously. The magnitude of the torque or force on the rotor is controlled by the magnitude of the current.

In this Project, you are asked to power the DC motor with the DCU. The DCU is an electronic device that allows you to control up to six digital output lines for on/off control of motors and other DC electrical components. The DCU plugs into one of the digital connections on the interface and is powered by a separate DC power supply. A 9-pin, D-sub socket cable is supplied with the DCU, with bare wires on one end, for use in building projects. There are connections for all six digital lines, plus a power connection and two ground connections. The color code of the wires is identified on a label attached to the cable.

The Digital Express VI can be used to control the DCU. You must send an output pattern indicating which digital lines should be on or off at any one time. You can determine the correct patterns to turn your motor on and off by sampling all 16 different output patterns in the configuration window of the Digital Express VI.

You can control the rotational speed of the motor by varying the voltage to the motor with a potentiometer. A potentiometer is a variable resistor often found in stereos to control volume in some speaker systems. A potentiometer is composed of a carbon film or fine wire windings, usually in the shape of an incomplete circle with two terminals on either end. As a wiper arm connected to a rotating shaft sweeps between the two terminals, the resistance in the circuit (and consequently the voltage to the motor) is varied.

In this Project, you will be using the Vernier Photogate to determine the speed of the motor. The Photogate is an electronic sensor that sends a +5V signal when a beam of light is passed uninterrupted between the two arms of the gate. To use the Photogate as a tachometer you will need to attach a propeller to the motor shaft and have it interrupt the light as the motor turns. We will measure the time between successive blockings of the Photogate by the propeller. Be aware that simply measuring the time from one beam interruption to the next will not yield an accurate measure for the rotational period. You must multiply the length of time by the total number of blades on your propeller.
Taking Measurements with the Photogate

SensorDAQ

The SensorDAQ has only one digital port capable of accepting BTD connectors. Since you will be using this digital port for the DCU, you must monitor the Photogate from the general-purpose counter/timer on the screw terminal (screw terminal 7) using the DAQ Assistant Express VI. When the DAQ Assistant (located in the Measurement I/O ➤ DAQmx – Data Acquisition palette) is placed on the block diagram a configuration window appears asking you to select the type of task. You will be Acquiring a Signal using the Counter Input. For this exercise, you should choose the Period option.

![Configuration window for the DAQ Assistant](image)

Next you must select the channel. If the SensorDAQ is connected to the computer and powered on, the channel name “ctr0” will appear in the configuration window. The final step is to configure the DAQ Assistant for Period Timing. Use the following to set settings: Starting Edge is Rising, the Max Signal Input Range is 100 seconds, and the Min Signal Input Range is 100u. The “u” is shorthand notation for “microseconds.”

LabQuest or LabQuest Mini

A second Digital Express VI can be used to take measurements with the Photogate if you are using the LabQuest or LabQuest Mini because these interfaces have two digital ports capable of accepting BTD connectors. You will need to place separate Digital Express VIs on the block diagram for the DCU and the Photogate. When you place the Digital Express VI on the block diagram, a configuration window appears. To use the Photogate as a tachometer, select Period Timing. This will set up the VI to measure the time between successive blockings of the Photogate. For both Digital Express VIs you must indicate the proper channel number for the DCU and Photogate.

PROJECT TIPS

1. Remember that the Photogate measures the period in seconds, but you are asked to display rotational speed in revolutions per minute (rpm).

2. On the Express VI used for photogate timing, you will see an input terminal labeled Timeout. This input controls the time that the VI will wait for the timing event. By default, if you do not wire it, the value is 10 seconds. For this Project and Challenge, we recommend 2 seconds.
3. Avoid using the Abort Execution button to stop your VI, because some of the DCU lines may remain on.

4. When building devices, you should always keep the power limitations of the DCU in mind. This limit is 1000 mA total current. Your device should also not exceed the electrical current limit of the power supply.

5. If you are using a LabQuest or LabQuest Mini with an older DCU, you may notice that lines D3 and D4 stay on, even when your program is not running.

6. Refer to Appendix E for additional information on the Vernier Photogate and DCU.

PROJECT TROUBLESHOOTING

1. Make sure that only the tip of one propeller blade blocks the Photogate at any one time. The Photogate must pass from a blocked to an unblocked and back to a blocked state in order to measure the period of revolution accurately. You can use the small red LED on the top of the Photogate to monitor the status of the gate. The LED will be on when the Photogate is blocked and off when the Photogate is unblocked.

2. Make sure the DCU is receiving power. The green LED in the top of the DCU box will be lit when the DCU is powered on.

3. Double-check the DCU cable connections against the color-coded label attached to the cable. Make sure you are using the right line for powering the motor.

4. Make sure you are using the same SensorDAQ that was connected to the computer when you configured the DAQ Assistant. Switching SensorDAQs will cause an error (#-201003 or -200478) when you run your program. See Appendix F for information on how to resolve this problem.
SENSORDAQ CHALLENGE DESIGN REQUIREMENTS

Note: Do not attempt the Challenge until you have completed the Project Design Requirements.

Connect the motor directly to the DCU (remove the potentiometer) and write a LabVIEW program to vary the input voltage to the motor using pulse-width modulation. Your device should operate like an analog control system allowing the user to adjust the effective voltage from a front panel control.

Note: The LabQuest and LabQuest Mini do not have the capability to generate a high-frequency pulse train. Therefore, an alternative Challenge for LabQuest and LabQuest Mini users is explained below.

SENSORDAQ CHALLENGE SETUP

Build the motor circuit

1. Remove the potentiometer from the circuit set up in the Project.

2. Connect the DC motor to the D1 and GND leads on the DCU cable as shown in the diagram below.

![Wiring diagram for a pulse-width modulated motor circuit](image)

Figure 6  Wiring diagram for a pulse-width modulated motor circuit

SENSORDAQ CHALLENGE BACKGROUND INFORMATION

Another way of varying motor speed when using a digital controller like the DCU is by using a method called pulse-width modulation (PWM). In PWM, a short, typically 1–2 millisecond, pulse is sent from the controller such that the voltage is on for a portion of the pulse and then off for the remainder of the pulse. When these pulses are sent to the motor at a high frequency, the average voltage to the motor is reduced and it operates at a slower speed.

The ratio of “on” time to total time is called the duty cycle. In the example shown below, the pulse is “on” for 60% of the time. If the supply voltage is 10 volts, this translates to an effective voltage of 6 volts.

![Pulse-width modulated signal](image)

Figure 7  Pulse-width modulated signal

The SensorDAQ Digital Express VI contains an option for Pulse-Train Generation when configuring the DCU. The input to this Express VI is the duty cycle formatted as a decimal number between 0 and 1.
LABQUEST & LABQUEST MINI CHALLENGE REQUIREMENTS

Note: Do not attempt the Challenge until you have completed the Project Design Requirements.

Modify your circuit so that your motorized propeller can be run at three distinct speeds: high, medium, and low. Then write a LabVIEW program to act as a 3-speed fan controller. You should continue to use the DCU to power the motor and the Photogate to measure the speed, but substitute two simple resistors in place of the potentiometer. Provide as much variation of motor speed as possible.

Note: When a Photogate is connected to the screw terminals of the SensorDAQ, the DCU patterns are limited, so you cannot do this Challenge with SensorDAQ. See above for an alternative Challenge for SensorDAQ.

ADDITIONAL MATERIALS

5 Ω resistor  
10 Ω resistor  
two diodes

LABQUEST & LABQUEST MINI CHALLENGE SETUP

Build the motor circuit

1. Remove the potentiometer from the Project circuit.

2. Connect the resistors, diodes, and DC motor to the D1 and D2, and GND leads on the DCU cable as shown in the diagram below.

![Wiring diagram for resistor/diode-controlled motor circuit](Figure 8)

LABQUEST & LABQUEST MINI CHALLENGE BACKGROUND INFORMATION

In the Project, you created an analog control system with a potentiometer to adjust the motor speed through a wide range of values. In this Challenge, you are asked to limit your motor to three distinct speeds resulting in a digital control system. When using the DCU as a power source, the voltage to the motor is either full on or off. In order to vary the motor speed in discrete steps, two different resistors must be connected to the output lines of the DCU. Sending power through the resistors either singly or in pairs creates three distinct voltage drops across the motor, which change the speed of the motor, just as the potentiometer did in the Project.

Referring back to the circuit diagram in Figure 8, you can see that the resistors are wired in
parallel. The equivalent resistance for a parallel circuit using two resistors is given by:

\[ R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2} \]

When resistors are wired in parallel, their equivalent resistance will always be smaller than the value of any single resistor. Since resistance is inversely proportional to motor speed, the smaller the resistance, the faster the motor will spin.

You will need to send several different output patterns to the Digital Express VI to control the speed of your motor (refer to the table below). Turn on DCU line D1 for one speed, turn on line D2 for a second speed, and turn on both lines at once for a third speed.

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<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
<th>D5</th>
<th>D6</th>
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Table 1 Digital output patterns for the DCU

There is one small difficulty that needs to be overcome. The two DCU lines will be attached to the same side of the motor. If you send one DCU line high, while the other DCU line is low, then the current could simply flow in a short circuit from one line to the other, bypassing the motor. To avoid this problem we use diodes. A diode is an electrical component that restricts current to flow in only one direction. It works in an analogous way to a check valve in water flow. If you put a diode in each of lines D1 and D2, you will prevent the backflow of current.

**CHALLENGE TROUBLESHOOTING**

1. Make sure you are sending the proper output pattern to turn on one or more DCU lines.

2. When labeling your front panel controls, remember resistance is inversely proportional to motor speed – the larger the resistance, the slower the motor speed.
Vernier Lab Safety Instructions Disclaimer

THIS IS AN EVALUATION COPY OF THE VERNIER STUDENT LAB.

This copy does not include:

- Safety information
- Essential instructor background information
- Directions for preparing solutions
- Important tips for successfully doing these labs

The complete *Engineering Projects with NI LabVIEW™ and Vernier* manual includes 12 projects as well as essential teacher information. The full lab book is available for purchase at: http://www.vernier.com/cmat/epv.html