**A Deconstructed Apparatus for Exploring Rotary Optical Encoders**
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## Presenter information

Feel free to contact the presenter for help or ideas in applying these topics in your classroom or lab.

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## Summary

This demonstration features a platform that can be used to teach and experiment with virtually any application that utilizes a rotary optical encoder. The robust, yet user-friendly design is durable and allows for visual observation of the inner workings of an encoder apparatus. It includes a DC-motor, encoder wheel/disk, and one or two optical interrupter sensors. An enclosure box provides all the necessary mechanical mounting, while aligning and protecting the disk and sensors inside. Openings in the box allow for observation and manipulation of the enclosed disk.

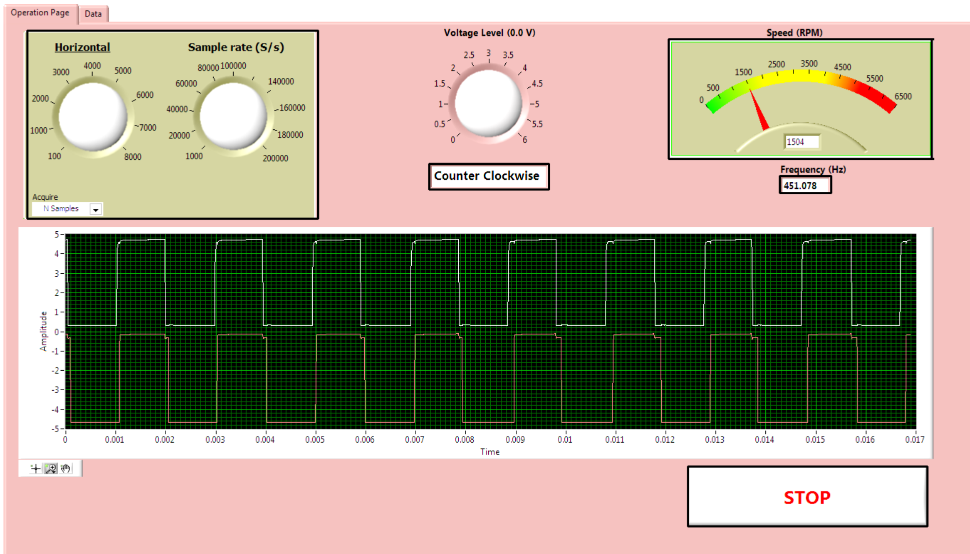
## Pedagogical Context

Rotary encoders are powerful tools for sensing and controlling rotary motion. Often coupled with microcontrollers, data acquisition tools, and/or control systems, they are widely utilized in robotics, machine design, automation, and nearly any application where rotary motion must be measured, tracked, and/or used as control feedback.

The hardware is designed to be robust and easily-maintained for long life expectancy in the harsh student lab environment. It is mechanically durable and sensors can be current-limited and diode-protected from reverse voltage. Construction is readily manageable with typical engineering lab resources. With the exception of the encoder disk (which can be machined or fabricated in-house with a 3D printer), all parts are inexpensive, off-the-shelf components. The assembly is modular and parts can be easily replaced or repaired. Total cost per unit depends primarily on disk fabrication costs, but it is typically less than $25.

## Sample Applications

1. ***Basic encoder functionality***: Observing by physically manipulating the encoder wheel and watching the sensor output with LEDs or on-screen as it is turned:
   - Passing each side of the hole into or out of the light beam generates an edge transition
   - Interpreting a stream of transitions as data communication
   - Phase relationship between two sensor signals differs with CW/CCW rotation
   - Resolution and regularity issues (quantity and spacing of radial holes) and sampling rate requirements (the more holes in the wheel the greater the minimum sampling rate)
2. ***Computer/microcontroller/software interfacing and data acquisition:*** The apparatus can be connected to a microcontroller, computer, and/or data acquisition module to analyze data and/or implement control systems with software such as Matlab, Labview, or native hardware operating systems.




3. ***Angular rotation:*** Using the apparatus as a motor, pendulum, and/or armature joint, measure/track angular change as the apparatus is manipulated by the observer or its intended application environment. (The basic unit is a motor-encoder combination. By using a motor with an extended or double-ended shaft, a pendulum/armature-encoder can also be created.)

4. ***Rotational speed:*** The motor can be driven by a DC power supply so participants can observe the RPM change as the voltage changes. A plot can be generated with the data.

5. ***Rotational direction:*** Using the software or microcontroller (and/or oscilloscope or logic analyzer), both sensor signals can displayed on-screen while the motor is turned forward and backward. Rotational direction is determined through quadrature decoding by studying the phase relationship between the two signals.

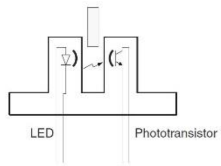
6. ***Motor drive control:*** Using motor driving techniques and feedback from the encoder, a program can attempt to move the wheel from one angular position to another. Rather than using the motor to drive the encoder, this apparatus is adaptable to a fan-controlled pendulum for demonstration of the armature motion concept.

7. ***Motor speed control:*** As a demonstration of the cruise control concept, the programmer could enter a desired speed into the program which will drive the motor to achieve and maintain that speed. This activity can be combined with an A-D conversion experiment by using a potentiometer to generate a varying voltage which is digitized and interpreted by the program as a speed control device.

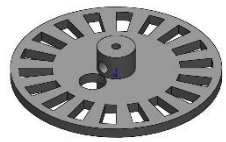
8. ***Additional topics:*** Further exploration, as desired, in combination with demonstrations above:
   - A-D and D-A conversion [#2-7]
   - Data logging, plotting, analysis, etc. [#3-7]
   - Control algorithms and system response (overshoot, damping, etc.) [#6-7]
   - Pulse Width Modulation as a motor drive technique [#6-7]

### Apparatus Design

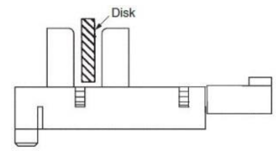
This apparatus uses an optical interrupter sensor consisting of a light source (LED) paired with a light detector (phototransistor) that outputs a high or low digital signal dependent upon whether the light path is continuous or interrupted.[1] An opaque disk with holes (or transparent sections) regularly-spaced around its circumference is attached to a rotation source (such as a motor shaft) and rotates within the sensor's beam path such that the holes pass through beam in succession, either passing or blocking the light as they enter and exit its path. Essentially it serves as an optical gate. By sending simple HI/LO logic level transitions for each pass/block event, the sensor can communicate angular change, rotational speed, relative positioning, and a host of other useful data. When used in pairs, the sensors can also communicate rotational direction (aka quadrature encoding).




Generic optical interrupter sensor[1]



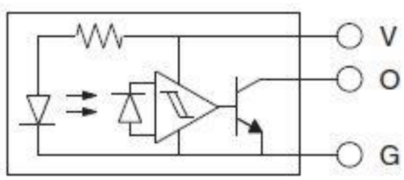
Encoder disk/wheel with 18 holes (20º rotation per hole, 10 º per edge)



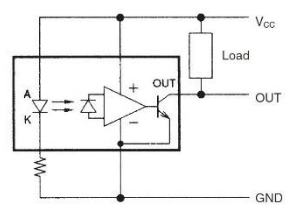

Actual optical interrupter used, showing disk/wheel between emitter and sensor[2]

## Electronics

The electronic functionality is accomplished with the optical interrupter sensor and some external circuitry. The internal sensor circuitry is split into two halves. The LED circuit provides illumination that projects through the holes in the encoder disk (or is blocked by the solid material between holes).[1] The model chosen for this apparatus uses an infrared (non-visible) LED emitter which is current-protected internally with a resistor (some models require an external resistor). [2] The phototransistor circuit senses when the emitted light is projecting through a hole or not. This model uses an open collector design where the emitter is tied to the ground connection such that when exposed to light it provides continuity from the collector (connected to the output pin) to ground. The external circuitry therefore is designed such that the load, such as a measurement apparatus or, in the case of the demonstration, an LED indicator, is connected between the $V_{CC}$ input and the collector (output pin).

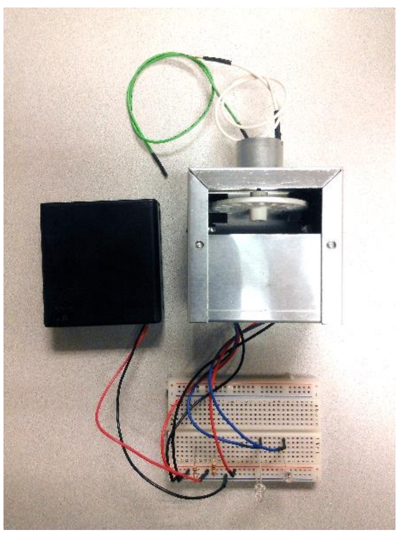



Internal circuitry of sensor used
(in this case with internal current-limiting resistor)[2]



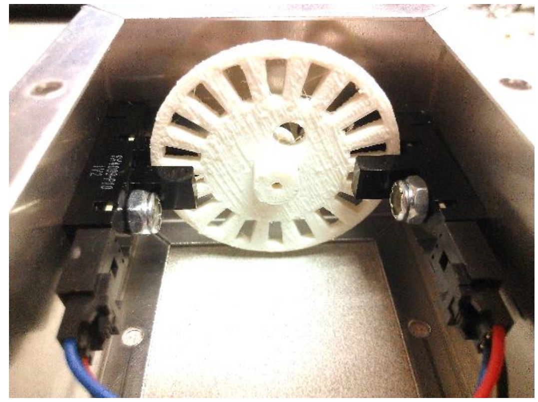

Internal/external circuitry of generic open collector model (this one shown with external current limiting resistor not needed in the specific unit used)[3]

## Hardware



The structural basis for this apparatus is a simple aluminum project box. The snap-in cover is trimmed to allow easy observation of the internal parts and manual rotation of the wheel. The cover helps protect the inner components and provide strain relief for the wires. For better observability it can be removed, but the units survive storage and handling better when the covers are replaced after use.

The motor shaft protrudes into a hole centered in the top face of the box. Mounting screws attach the motor from the inside. The disk was manufactured on a 3D printer (or can be machined). The shaft hole in the wheel's hub is sized so that it presses onto the shaft. A hole in the wheel's hub, perpendicular to the shaft, was also provided for a threaded insert and set screw, but that was not needed for this application which experiences minimal torque. The friction alone is enough to spin the wheel. With such a minimal load, a very light duty DC motor can be used, which also keeps the current requirements minimal, enabling some microcontrollers and data acquisition units to drive it directly. Some motors will require an external amplifier or motor driver.



The interrupter sensors are mounted on the side flanges of the box such that the wheel spins between the gates of each sensor. One mount is offset slightly so the sensors are positioned such that the output signals are neither exactly 90 º nor 180º out of phase with each other. This provides the observable phase shift necessary for quadrature (direction) decoding capability. Connectors are used for easy replacement of either a sensor or wiring harness, which is a substantial maintenance convenience (these sensors can be sensitive to reverse polarity connections, so it is advisable to use protection diodes and/or build to facilitate easy sensor replacement).

The hardware design can be customized as desired to meet the needs of various applications. For example, different motors could be used to match various equipment or load requirements; the encoder wheel can have as many or few holes as needed for the resolution requirements and sampling capabilities; the sensor can be substituted with alternates to meet other mechanical or electrical requirements.

## Bill of Materials

| Part | Description | Manufacturer | Mfg. Part # | Vendor | Vendor part# | Price | Qty | Ext |
|---|---|---|---|---|---|---|---|---|
| Optical interrupter sensor | Slot type Photointerrupter - Logic Output - Transmissive - Open Collector / Light-ON | Omron | EE-SX4009-P10 | DigiKey | OR630-ND | 7.1 | 2 | 14.20 |
| Connector | C-Grid Connector housing, Female, 3-pin | Molex | 50579403 | DigiKey | WM2901-ND | 0.19 | 2 | 0.38 |
| Connector pins | C-Grid connector terminal pin, female | Molex | 16020102 | DigiKey | WM2510-ND | 0.17 | 6 | 1.02 |
| Breadboard pins | DB Male Crimp Pin, High-density | | | MPJA.com | 16269 PL | 0.05 | 6 | 0.30 |
| Wire | Stranded hookup wire, ~22AWG or similar | Any | | | | | 6 | 0.00 |
| Box | Aluminum box, 2.75x2.75x2.125" | LMB Heeger | J-871 PL/UNPD | Digikey | L112-ND | 5.36 | 1 | 5.36 |
| Motor | DC motor (as low current as possible) | Jameco Reliapro | RF-310TA-11400 | Jameco | 238465 | 2.95 | 1 | 2.95 |
| Motor mount screw | M2x3mm (depends on motor choice) | McMaster-Carr | 92005A11 | McMaster-Carr | 92005A11 | 0.05 | 2 | 0.10 |
| Star washer | For motor mount screw | McMaster-Carr | 93925A210 | McMaster-Carr | 93925A210 | 0.03 | 2 | 0.06 |
| Wheel | Encoder wheel, 2" dia, hole count and spacing specified as needed for application | In-house (3d printed) | | | | | 1 | 0.00 |
| Threaded insert | If needed (if press-fit won't work) | | | | | | 1 | 0.00 |
| Set screw | If needed (if press-fit won't work) | | | | | | 1 | 0.00 |
| | | | | | | | | **24.37** |

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[1] *Photomicrosensors Technical Information*; Omron Electronic Components LLC, Cat. No. X305-E, p. 61
[2] *Photomicrosensor (Transmissive) EE-SX4009-P10*, Omron Electronic Components LLC, Cat. No. X305-E-1, p. 199
[3] *Photomicrosensors Technical Information*; Omron Electronic Components LLC, Cat. No. X305-E, p. 71