To: Professor Lu

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Subject: ME1049 Lab 01 Angular Displacement

Date: April 20, 2021

On 20th April, Edward Shen, Ian Li, Stanford Xue, and I conducted our first experiment in the course Mechatronics, from which we have explored angular displacement measurements using a potentiometer and an incremental encoder as shown in Figure 1.
For the first part - potentiometer, we understand the voltage dividing properties of the potentiometer. From Table 1, we can obtain the **calibration equation** for that potentiometer, which is shown in Equation 1. After fitting the curve, we can get that the **sensitivity of the sensor** is equal to $18.4\ \mathrm{mV/deg}$ as shown in Equation 2, which is the reciprocal of slope in Figure 2.
For the second part - incremental encoder, we have observed the behavior of signal A and B using different types of encoding and concluded into following items.

- Compare the behavior of signal A and B.
  The incremental encoder employs the quadrature encoder to generate its A and B output signals. The pulses emitted from the A and B outputs are quadrature-encoded, which means that when the incremental encoder is moving at the constant velocity and there is a $90°$ phase difference between A and B.
  At any particular time, the phase difference between the A and B signals will be positive or negative depending on the encoder's direction of movement. For a rotary encoder, the phase difference is $+90°$ for clockwise rotation and $-90°$ for counter-clockwise rotation, or vice versa, depending on the device design. This can be confirmed by observing the diagram of X4 encoding when rotating the encoder in the clockwise direction, which **match**es **state machine diagram** for X4 decoding algorithm as shown in Figure 3 and 4.
  The frequency of the pulses on the A and B output is directly proportional to the encoder's velocity; higher frequencies indicate rapid movement, whereas lower frequencies indicate slower speeds.

- Compare the difference for three types of encoding.
  With quadrature output, three kinds of encoding can be used: X1, X2, or X4. The difference between these encoding methods is just which edges of which channel will be counted during movement, but their **influence on encoder resolution** is significant. Although the **PPR** of the encoder is fixed, which is 24 pulses per revolution, different types of encoding can provide us with more choices of the need for resolution.
  With X1 encoding, both rising and falling edge of channel A is counted. If channel A is ahead of channel B, the rising edge is counted, and the movement is clockwise. On the contrary, if channel B leads channel A, the falling edge is counted, and the movement is counterclockwise. When X2 encoding is used, either rising or falling edges of channel A are counted. This doubles the number of pulses that will be counted for each rotation angle, which in turn **double**s the encoder's **resolution**. X4 encoding goes one step further, to count either rising or falling edges of both channels A and B, which quadruples the number of pulses and **increases resolution by four times**.
  All of above conclusions are obtained from the data in Table 2, which is the experimental data. And it matches the theoretical resolution calculated in Equation 3, 4, and 5.

After this experiment, we have learned a lot about the working principle of the potentiometer and incremental encoder - the tool for measuring angular displacement, which promotes the theories we have learned in class.

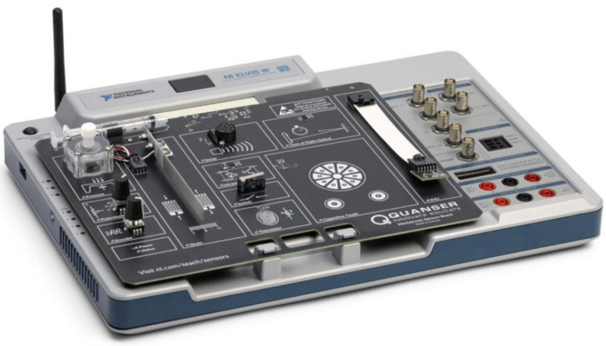

Figure 1: Quanser Mechatronic Sensors Board Used in Experiment.

Table 1: Recorded Potentiometer Measurements.

Angle (deg)	0	30	60	90	120	150	180
Output (V)	0.91	1.53	2.05	2.63	3.27	3.64	4.23

Calibration Equation for Potentiometer:

$$Y = 54.3X - 51.6 \tag{1}$$

in which X is the sensor output in V and Y is the pot angle in deg.
Equation for Sensitivity of Sensor:

$$\text{Sensitivity} = \frac{1}{\text{Slope}} = \frac{1}{54.3 \ \text{deg}/\text{V}} = 18.4 \ \text{mV}/\text{deg} \tag{2}$$

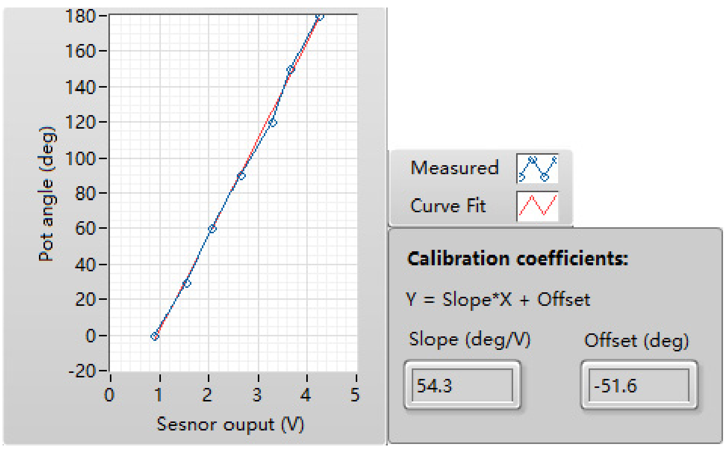

Figure 2: Fitting Curve of Sensor Readings.

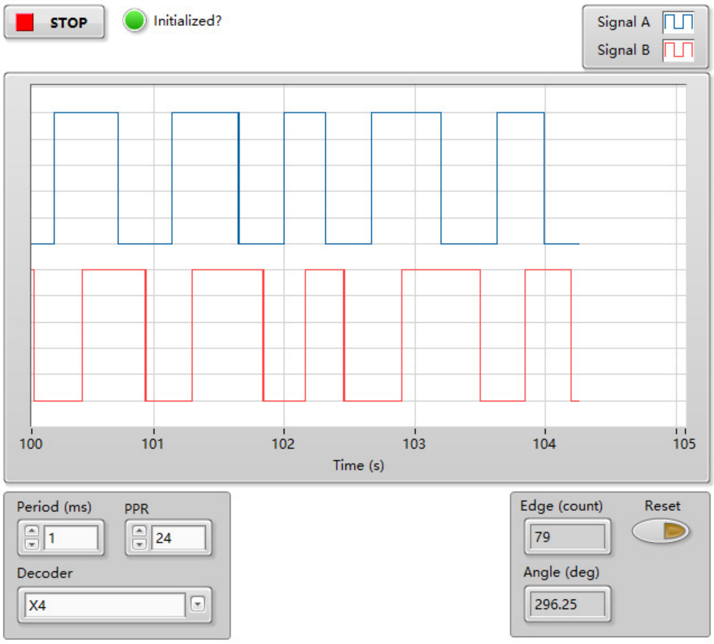

Figure 3: Diagram of X4 Encoding when Rotating in the Clockwise Direction.

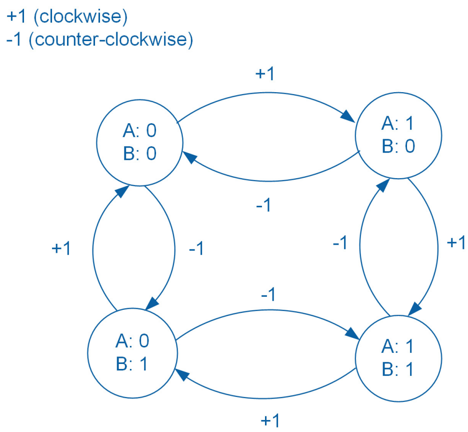

Figure 4: State Machine Representation of X4 Decoding Algorithm.

Table 2: **Angular Resolution** of Different Types of Encoding.

Types of Encoding	X1	X2	X4
Resolution (deg)	15	7.5	3.75

Equation for the Angular Displacement and Resolution:

For X1 ($N = 1$):

$$\Delta\theta = \frac{360\,\mathrm{deg}}{N \cdot PPR} = \frac{360\,\mathrm{deg}}{1 \times 24} = 15\,\mathrm{deg} \tag{3}$$

For X2 ($N = 2$):

$$\Delta\theta = \frac{360\,\mathrm{deg}}{N \cdot PPR} = \frac{360\,\mathrm{deg}}{2 \times 24} = 7.5\,\mathrm{deg} \tag{4}$$

For X4 ($N = 4$):

$$\Delta\theta = \frac{360\,\mathrm{deg}}{N \cdot PPR} = \frac{360\,\mathrm{deg}}{4 \times 24} = 3.75\,\mathrm{deg} \tag{5}$$