Actuation and Sensing Mechanisms in Robotics System

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Lab #3:
Development of a Single-axis Force Sensor using Strain Gauges

Part 1: Fabrication

In this portion of the lab, you will install strain gauges on an aluminum bracket. On the second part of the lab, you will calibrate the gauges in single Z direction. You will use a voltage divider method and an amplifier. The signal will be measured via Arduino.

Materials

- Arduino Uno board
- Breadboard
- Multimeter
- Jumper cables
- 2 strain gauges
- Aluminum bracket
- Sand paper (grit #220 and #400)
- Acetone
- Cyanoacrylate(Adhesive)
- Tweezers
- Signal amplifier or OP AMP
- Wood bar
- Sealing Tape

Experiments

1. Sand all the sides with alcohol of the bracket.
2. Clean the surface with acetone. Now you are ready to install the gauges.
3. Remove a gauge from the packet with the tweezers and place it on top of the packet facing upwards (Make sure you grab the gauge from the back side of the pattern).
4. Test the gauge with a multimeter to make sure there is continuous connection.

5. Press some scotch tape on top of the gage and remove it at a less than 45-degree angle away from the gage (The gage should be on the tape at this moment).
6. Tape the gauge to the desired position on the bracket (Make sure the position is clear from the pressing points of the testing machine (34SC1/Instron) and leaves some room for back side of the pattern).
7. Partially remove the tape, until the strain gauge is upside down. Then, apply Cyanoacrylate(adhesive) to the position where the strain gauge will be glued.
8. Press the strain gauge in place and wait a minute for the glue to dry.
9. Remove the tape gently starting on the side of the pattern, this time keeping the angle very narrow and towards the gauge.
10. Repeat for every side of the bracket, as seen in figure 1.
11. Glue back side of the pattern, making sure they do not conflict with the pressing points of the testing machine.
12. Once everything is glued together, solder the cables according to figure 2
13. Test every terminal to make sure there is continuous connection.

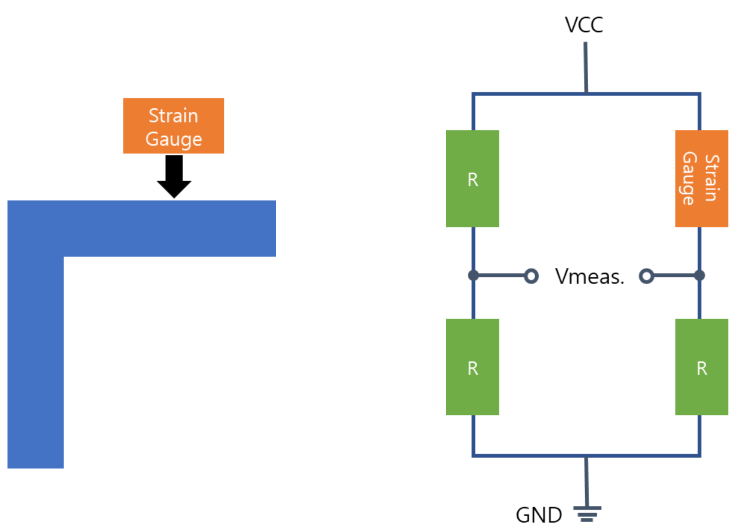

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Figure 1: The H-bridge circuit for reading voltage value from the strain sensors.

Figure 2 : Strain sensor on the L bracket.

Part 2: Calibration

1. Mount the bracket as shown in figure 3.
2. Develop a simple Arduino code for data receiving.
3. Apply a load by pressing a lever of testing machine.
4. Perform continuous readings starting at no load and ending at 80 N.
5. Use this data to find your calibration matrix. (**F**=**C S**)

Figure 3 : Test set-up of calibration.

Calibration Matrix calculation

F=C S

$$\boldsymbol{F} = [F\ ] = [F_1\ F_2\ \dots F_n]$$
$$\boldsymbol{S} = [S] = [S_1\ S_2\ \dots S_n]$$
$$\boldsymbol{C} = [C]$$

In order to find the calibration matrix, the system $\boldsymbol{C}=\boldsymbol{F}\,\boldsymbol{S}^{-1}$ needs to be solved. $\boldsymbol{S}$ is not a square matrix, so a pseudo-inverse method should be used.

Results

1. (5 pt.) Provide pictures of your bracket and experimental setup.
2. (15 pt.) Plot a graph for the parameters in the first configuration and a graph for the second. In other words, provide a plot of "Voltage output (V_{out}) vs. Applied force (F)."
3. (15 pt.) Provide your calibration matrix $\boldsymbol{C}$ (In this case, this is just a 1x1 matrix).

Discussion

1. (10 pt.) Describe the relationship in the graph. Are they linear? Why, or why not?
2. (10 pt.) Discuss the sensitivity of the signal.
3. (10 pt.) What kind of effect would misalignment of the strain gauge (if you have) cause? Is this a concern in your system?
4. (10 pt.) Discuss the advantages and limitations of using this type of strain gauge setup for force sensing.

Advanced Section

Now you know how to make a single axis force sensor using strain gauges. However, you are not really satisfied with this simple and super-easy lab and would like to try a multi-axis load cell. One simple solution is to have a L-shaped corner brace shown in Fig. 5(a) and attach four strain gauges on both ends extending the work from our lab, as shown in Fig. 5(b).

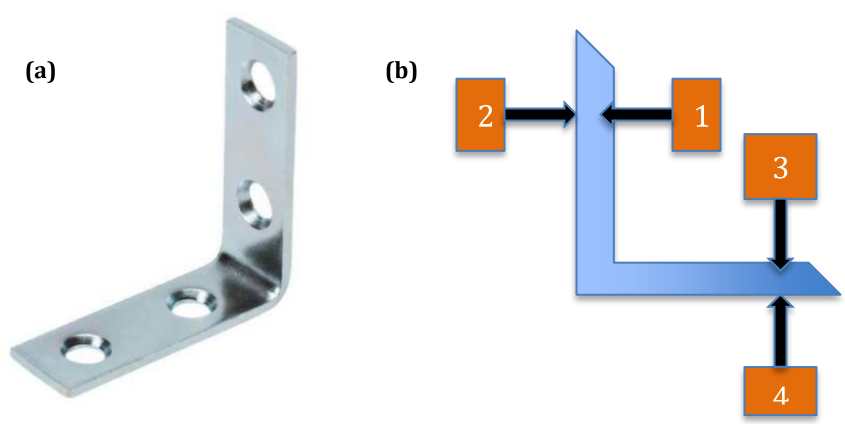

Figure 5 : Multi-axis force sensor.

Using the two same circuits you used in the lab, we can collect the force data for calibration. Since we are interested in measuring two-axis forces, we need to do the calibration process for each axis (one by one, not simultaneously), as shown in Fig. 6, and the results are shown in Table 1.

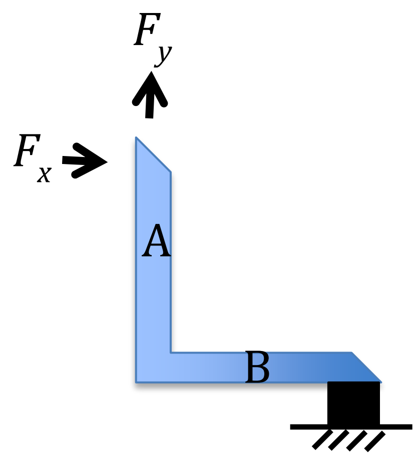

Figure 6 : Calibration of multi-axis force sensor.

Table 1. Calibration data of multi-axis force sensor

F_x	V_a	V_b
0	0	0
1	0.48	0.31
2	1.03	0.59
3	1.48	0.88
4	2.1	1.19
5	2.53	1.48
6	3.07	1.8
7	3.49	2.08
8	4.02	2.42
9	4.55	2.67
10	4.99	2.96

F_y	V_a	V_b
0	0.03	0
1	0.02	0.36
2	0.04	0.71
3	0.01	1.01
4	0	1.32
5	0.02	1.65
6	0.05	1.97
7	0.01	2.2
8	0.05	2.43
9	0.03	2.65
10	0.02	2.85

Discussion (continued)

5. (5 pt.) Are the force outputs (V_a and V_b) coupled? Why or why not?

6. (10 pt.) Find your calibration matrix ***C*** using pseudo-inverse. (Your ***C*** should be a 2x2 matrix this time.)

7. (10 pt.) Please find the determinant of your ***C***. What does the value of the determinant tell you?