Research Proposal: Load cell based automatic force measurement

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I. Big picture

In current LEMUR projects, two of them involve the measurement of force: a controllable flying vehicle with a single moving part, and MEMS actuated paper fold. The first project requires to measure force with maximum magnitude of 60g and resolution of 0.1g, while the second requires force with maximum magnitude of 10g and resolution of 0.01g. In both cases, the current solution is to measure the force through a digital scale and record the data manually, which is tedious and error-prone. Therefore, we need to find a way to automatically measure the force and record the data. Because load cells can transform forces into electric signals, we can construct a system based on this characteristic and measure force automatically.

II. Specific project scope

- What subset of the overall problem are you addressing in particular?
    - Automatically and accurately measure small scale forces
- How does solving this subproblem lead towards solving the big picture problem?
    - Will be helpful in projects that require force measurements
- What is your specific approach to solving this subproblem?
    - Assemble a system using load cells, MCU and converters to achieve automatic force measurement
- How will we know that this subproblem has been satisfactorily solved?
    - Force can be measured accurately when compared to digital scale, and data points can be recorded on a computer interface

III. Background/related work/references

Load cells are devices that transform forces into electric signals. The magnitudes of electric signals are directly proportional to the forces applied to the load cells. There are three different types of load cells: hydraulic, pneumatic and strain gauge. In this case, we are using a strain gauge load cell, whose resistance changes linearly in response to the force applied. With an additional Wheatstone bridge, it is easy to measure the output voltage. However, the output voltage is very small. For example, when a load cell has an output of 0.7mV/V, at excitation of 10VDC, the output at full load is 0.7mV/V * 10V = 7mV. It is too small for us to detect, so we need to amplify the signal to a measurable range. HX711 is a 24-bit analog-to-digital converter designed for weigh scales. The small-scale analog input is fed into the low-noise amplifier with gain of 128. Then, the amplified analog voltage signal is converted into 24-bit binary number which can be read by MCUs such as Arduino.

The load cell that we chose is a single-point load cell, where four strain gauges are placed on the four corners of the load cell. It is mounted by fixing the end of load cell with the wires, then apply force perpendicular to the load cell on the other end of the load cell, which is marked by an arrow. To achieve that, the cell is set up using a “Z” formation. The force is applied to the bar and the four strain gauges will measure the tensions and compressions on the load cell. The strain gauges are then connected using the Wheatstone bridge and the distortion is captured in the form of DC voltage signal.

- Strain: deformation per unit length $\epsilon = \Delta L/L$
- Normal Stress: $\sigma = F/A$
- Stress-strain relationship: $\sigma = E \cdot \epsilon$ E: Young's Modulus for the material
- Gauge Factor: measure of resistance change with strain $GF = \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\epsilon}$
    - The Gauge Factor for normal strain gauges is 2
- Bending Strain: $\epsilon_B = O_B/E$
- Moment stress: $O_B = F_v \cdot l/Z$
    - F_v: vertical load
    - l: length
    - Z: Sectional modulus for cross-section ($Z = bh^2/6$ for rectangles)
- Vertical load equation: $F_v = \frac{E\epsilon_B\left(\frac{bh^2}{6}\right)}{l}$

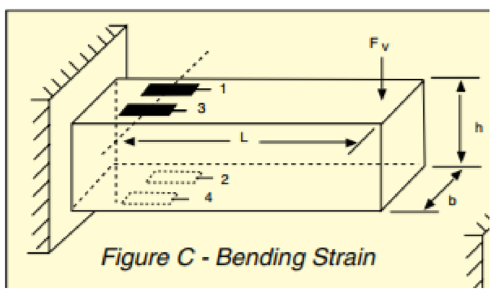


Fig. 14. Bending Strain demonstration

Source: https://www.omega.com/faq/pressure/pdf/positioning.pdf

Full bridge configuration, compute bending strain:

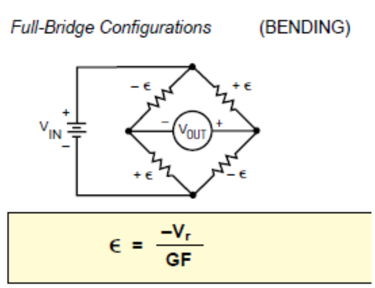


Fig. 15. Equation for bending strain under full-Bridge configuration

Source: http://www.omega.com/techref/pdf/StrainGage_Measurement.pdf

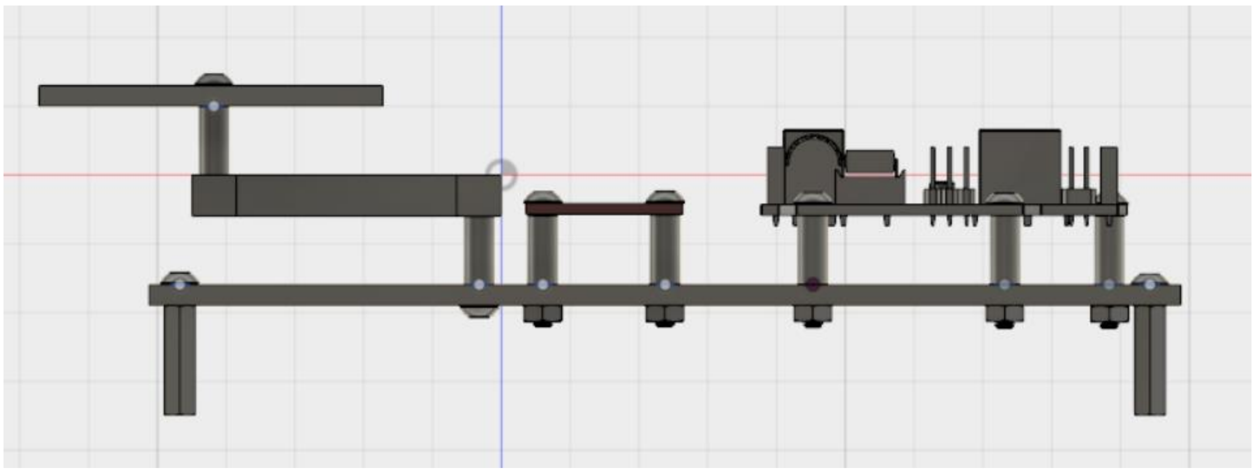
$V_r = [(V_{out}/V_{in})$ strained - (V_{out}/V_{in}) unstrained$]$

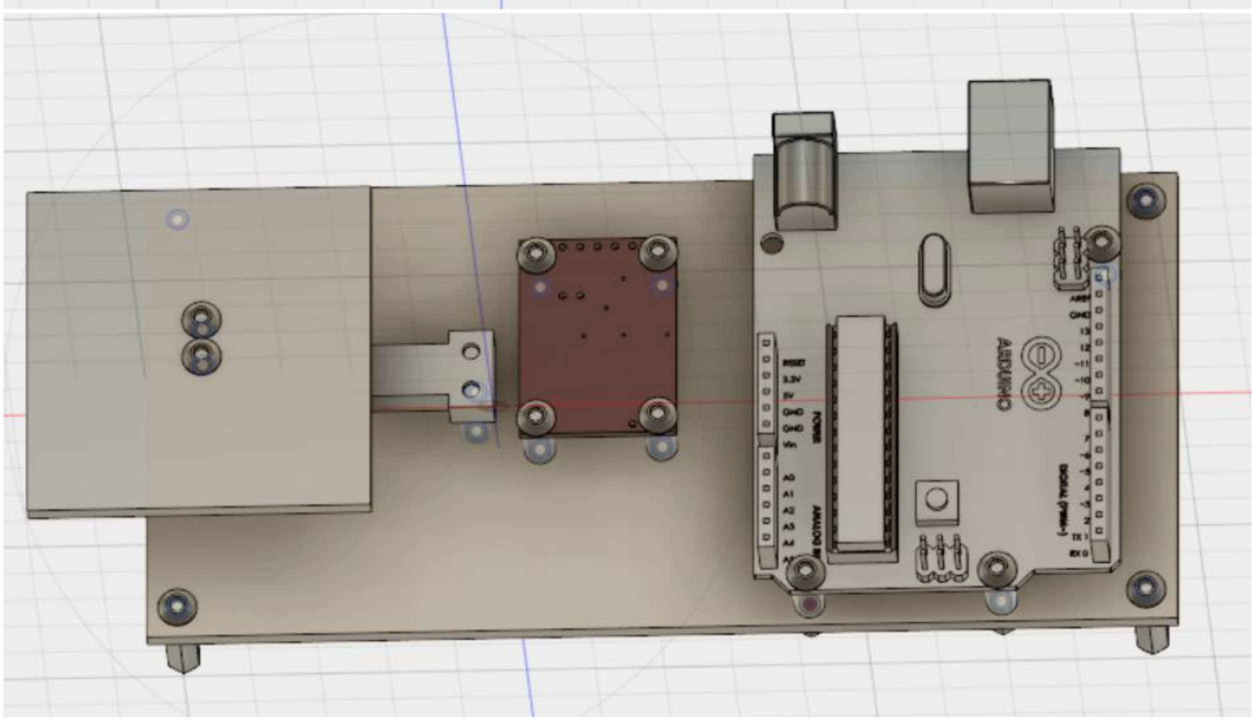
Reference:

1) Practical Strain Gage Measurement: http://www.omega.com/techref/pdf/StrainGage_Measurement.pdf
2) Positioning Strain Gages: https://www.omega.com/faq/pressure/pdf/positioning.pdf
3) Load Cell Primer: https://www.phidgets.com/docs/Load_Cell_Primer
4) How Sensors work – load cells: http://www.sensorland.com/HowPage005.html
5) HX711 Datasheet: https://cdn.sparkfun.com/datasheets/Sensors/ForceFlex/hx711_english.pdf

IV. Goals, deliverables, tasks

System 3D diagram:





Timeline:

1) Do experiment with scale on paper fold – completed on 6/4/2017
2) Do experiment with scale on crazyflie thrust – completed on 7/3/2017
3) Order load cell and ADC module on Amazon & Sparkfun – 1 week delivery
4) Assemble the system – 1 day
5) Test load cell (calibration, resolution, etc.) – 1~2 days
6) Do the paper folding experiment – 1 week
   Specific tasks:
   a. Setup mounting
   b. Calibration
   c. Experiment routine
   d. Data recording
   e. Problem solving (potential noise?)
7) Do the crazyflie thrust experiment – 1 week (Similar tasks)