Abstract

A sensor taped to the knuckle of the puncher was used to measure force in a punch when the puncher was wearing a boxing glove and hitting a pad held by a partner. The data from this impact was collected by a DAS using Matlab and analyzed quantitatively and qualitatively.
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Summary

In this lab we created an experimental setup to measure the force from a punch. We used a sensor that had a decrease in resistance when a force was applied. This change in resistance was converted to a voltage through a op amp drive circuit. Since a punch is dynamic event, we used a Matlab as a DAS to sample the voltage of the drive circuit at a high sampling rate and record the event. We did this for multiple trials and saved the data for analysis in excel. From this data we calculated the min output voltage which corresponded to the maximum force and also practiced integrating the data in excel so in the future we can integrate the force over time to obtain the momentum transferred from the punch.

Introduction

This lab project was intended to provide initial data on the impact incurred when punching in training. This data can be used to create the design specifications necessary to capture this impact in a wireless system which will be made as a senior project. This lab also provided an opportunity to show proof of concept and make sure that our sensor/op amp configuration is suitable to the task of measuring this impact. Since this impact typically occurs very quickly we must sample our system very quickly, so we started sampling at a high rate of 100kS/sec. Another challenge was to find a sensor that could measure the impact and not hurt the user or damage the sensor. After a lot of research we found a flexible sensor that was suitable for this experiment. After some initial difficulties we were able to do multiple trials very quickly and analyze the output in both Matlab and Excel.

Apparatus

MatLab and custom data acquisition program, ‘Punchforce’
DC power supply
Oscilloscope
Flexiforce sensor
741 op amp
100k resistors
Boxing gloves
Training pads
Electrical tape

Procedure

We inserted the sensor in an inverting opamp configuration shown below.

\[ V_{\text{out}} = -V_t \times \left( \frac{R_f}{R_s} \right) \]

Instead of a negative \( V_t \) we used a positive 5V so our \( V_{\text{out}} = -5(R_f/R_s) \). As our \( R_s \) decreases with force, our \( V_{\text{out}} \) becomes more negative. Some testing
was done to make sure our Rf was lower than our Rs so our op amp would not saturate. For our experiment we used an Rf of 200k.

**Experimental steps:**

- Started up Matlab and ran the punch_lab program
- Set up experimental apparatus, including taping sensor on top of the knuckle of the middle finger.
- For the first couple of trials, used 100,000 and 10,000 for the sample rate and number of samples.
- After inputting all the parameters, have one person be ready to hit the punching bag and another ready to initiate the Matlab program.
- After initial trials, we ran the experiment using 10,000-333ks/Sec for the sample rate and number of samples.
- After several trial runs, imported the data from Matlab into excel.
- Using Excel, graphed the data and filter out unwanted data points.
- Re-graphed the region with the relevant data points.
- Calculated area under the curve for each trial.
- Found the minimum voltage for each trial.
- Calculated the averages for both minimum voltage and area under impact curve.
- Calculated the standard deviation for both.
- Traced front of fist onto graph paper to find the approximate area of impact.

In order to be able to analyze the data on excel, several formulas were used:

```
“=ABS(B4*$E$2)“    - Vout * time = change in voltage across the curve.
“=SUM(C4:C416660)“   - Total change in voltage across the curve interval.
“=MIN(B4:B416660)“   - The minimum voltage value across the range of voltages.
```

After finding all the values for all twenty-four of the trial runs, we were able to then consolidate and find averages and standard deviations from all the spreadsheets. All those pieces of data were then put on a separate spreadsheet.
Results

Graph 1.a Sample of transient response from Matlab
Graph 1.b  Sample of peak force zoom in
Graph 1.c Sample of peak force super zoom in
Graph 1.d Peak when sampled at 333Hz

Graph 2.a Sample of graphing in Excel

First impact area = 3550mm^2
Area of sensor = 71.3306mm^2
Number of sensors that can fit on impact area = 3550mm^2 / 71.3306mm^2 = 49.768
Min Vo = -1.34

\[ V_o = -\frac{R_F}{R_s} V_i \]
\[ R_s = \frac{R_F V_i}{V_o} = -\frac{200\Omega \ast 5V}{-1.34} = 746.269k\Omega \]

Using the graph of Rs vs Force provided by the manufacturer

![Graph showing Rs vs Force](image)

We estimate 746kohms to correspond to 7.5lb-f.

(peak force/per sensor) * (number of sensor that fit on impact area) = total peak force on impact

So,

(7.5lb-f) * (49.768) = 373.26lbs of force

**Discussion**

**Qualitative analysis**

Some of the important information obtained from this experiment was not represented in strict numerical values. For example, before performing the experiment we had not idea how long the impact of punching the pad would last but expected it to be extremely short. What we observed was that a typical impact lasted 1 to 2 tenths of a second, much longer than we expected. We were also interested in observing the peak force of the impact and again
expected it to be extremely short. It was very short, but still longer than we expected. Looking at Graph 1.c we can see a zoom in view of the peak force. Here we see oscillations due to noise, but we get peak readings for about 1millisecond. This means we can sample at a sampling rate lower than 100kS/sec and still get the peak value, which is very good because in our application we will not be able to sample at 100kS/sec. The data sheet for the sensor says that the response time for the sensor is less than 5microseconds so we also know the sensor most likely responds fast enough for our application.

Problems encountered

We encountered one major difficulty in this experiment. When initially testing our experiment we were getting spikes out the output after an impact that often went positive in value which should not happen in the op amp configuration we used. Eventually we realized that this was probably due to noise being injected into the input of the op amp and then being amplified. One cause of this noise was our noisy DC power supply. Another factor in having such a large amount of noise is the fact that we had to use very long wires to connect the sensor to the op amp, which caused couple and made the chance of injecting noise into the input of the op amp very high. I was very curious about this because we noticed that if someone touched the negative input to the opamp there would be huge spikes at the output. I investigated this phenomenon holding one of the probes to the oscilloscope with my hand and letting the other probe hang in the air. I found the voltage to be around 200mV at 60hz, and the amplitude of this voltage would noticeably increase if I stood near powered devices such as computers. Hopefully in our application we will have a very short lead between the sensor and the input or isolate the wires well to avoid noise from touching the input and so forth.

Uncertainties in measurement

One of the problems with our measurement came from a noisy output, primarily due to a noisy power supply. The following are some of the instruments that we used and their respective uncertainties.

Flexiforce - +/- 2.5%
DC 5v power supply - +/- 200mV
100k Ohm resistor - +/- 5%
DAS – resolution of 0.2% sampling at 12 bits

Improvements

We requested data of Rs vs Force from the sensor manufacturer but all we received was a graph that we could use to visually estimate force. If we had received the actual data values of Rs vs. force for a typical sensor we could have quickly found the equation that accurately related Rs and force and used this equation in excel to convert all the values of Rs to force. Rs can easily be calculated as it was in the Results section of this report as

\[ Rs = \frac{R_s V_i}{V_o} \]

If we had all our data in Force instead of voltages our data would be more meaningful and we could integrate to get the change in momentum. Even though we didn’t have all the data in terms of Force, we still integrated our voltage over time which was good practice.

The graph of Rs vs Force provided by the manufacture was not very useful because many of our Rs values were not shown because they were too high. This could be due to very light impacts due to light punches, the person holding the pad not holding it stiff enough or not distributing enough of the impact on the sensor area. In the future we expect to receive the data from the manufacturer of Rs vs. Force.

Quantitative results

In the results section a sample calculation of the max force is shown when the voltage was Vo= -1.34V. The result was 373.26lbs of peak force for the punch which is very reasonable compared with 2381N (535lb force) predicted by Smith and considering our collision was very elastic in nature. This predicted peak force was also calculated based on the assumption that the force is equally distributed across the whole surface of the fist, which is not completely accurate. Also the area of the fist was a very rough estimation, which can be seen in the appendices.

Since most of our voltages were very low in amplitude, the corresponding resistances were very small and could not be evaluated for the corresponding force in the Rs vs. Force graph. It is also possible that the sensor was not giving accurate results because of it’s placement on the knuckle. If we were to redo the experiment we might place it on the flatter part of the surface of
impact on the finger.

We could also calibrate the sensor ourselves, but this would be an experiment unto itself. We would need a very large range of weights and a puck to distribute the force over a very small sensing area.

**Conclusion**

We had some initial problems performing the experiment because we got large spikes of noise at the output, but in the end we got good data and learned some things that can help us when designing this kind of system again, such as isolating the inputs of op amps from noise. Once we got a clean signal of the impact at the output it was very satisfying and instantly gave us some interesting data. One of the most promising conclusions we came to after observing the signal output was that we don’t need to sample at an extremely high rate to get meaningful data of the impact of the punch. We also got experience editing the Matlab data acquisition program, and setting up the DAS on our own. In the end we determined that the flexiforce sensor does work for measuring the force in a punch, but we must be very careful in the the setup of our drive circuit.
References

A.J. Wheeler, June 2000 w/ 12/7/01 updates, *Engineering 300 Laboratory Syllabus*
San Francisco State University

Smith, M.S.; Dyson, R.J; Hale, T., *Development of a boxing dynamometer and its punchforce discrimination efficacy-

Appendices

Table 1.a Sample of Excel sheet

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Experimental Setup
Trace of fist area
\[ V_0 = \frac{S}{R_0} \]

\[ \frac{12 \times 16}{192} = 142 \times 25 \text{mm}^2 \]

\[ = 3550 \text{mm}^2 \]

\[ = 69.76 \text{mm}^3 \]

\[ V_0 \times t = 2 \times F \times t \]

\[ \text{Springing} \]

\[ a = 41.76 \text{mm} \]

\[ k = 7.17 \text{mm} \]

\[ A = 7.17 \text{mm} \]