IMU-Based Barbell Activity Tracking

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Imagine This…

- Andrew is an intermediate weightlifter who's been trying to make his workout routine more "seamless"
- One of his biggest pet peeves is manually having to add his rep count and weight after every cycle, disrupting his flow
- Given that he has plenty of experience with weight-training already, he has a general idea of his personal expectations and wants to stay consistent for now

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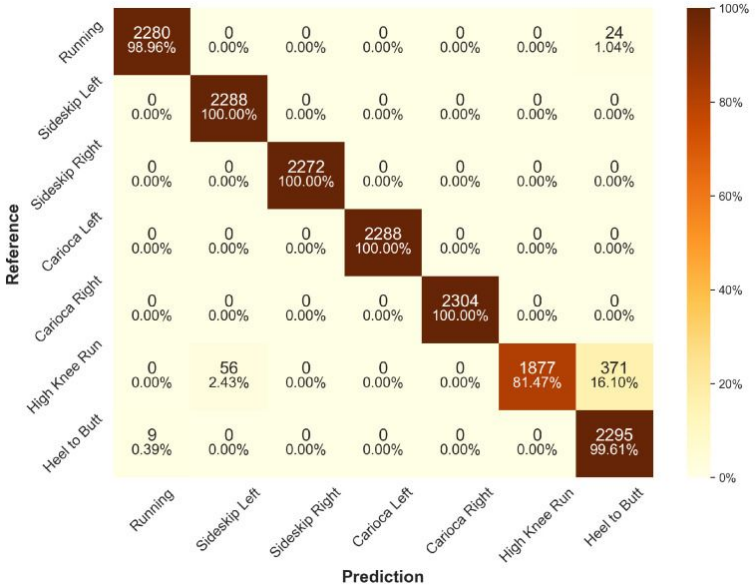
Cardio Activity Tracking

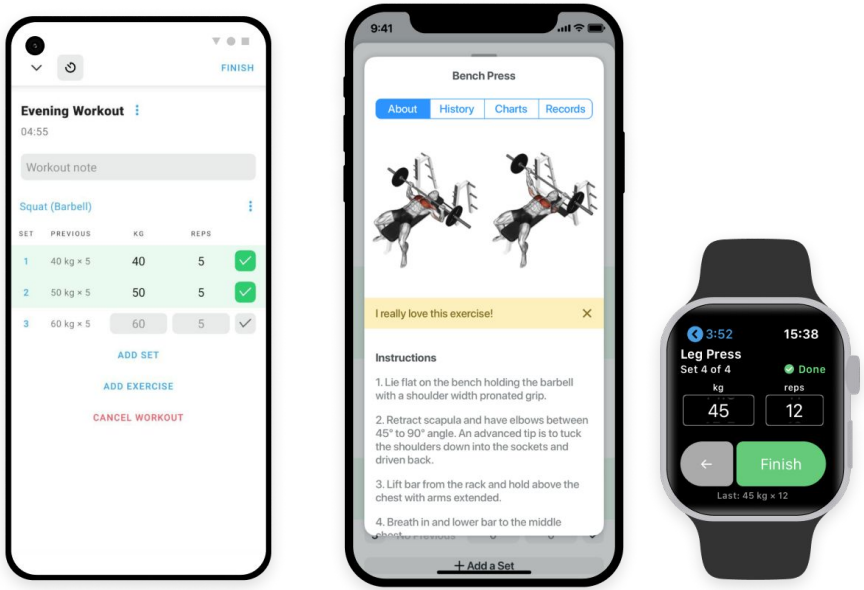
- Apple watch tracks time standing/moving/exercising



IMU-Based Fitness Activity Recognition Using CNNs for Time Series Classification (2024)

Weightlifting Activity Tracking

- Experienced lifters log sets/reps/weight/type of exercise to help reach goals
- Watches only help log exercise completion after entering plan into app
- Goal: Develop a system to automatically log all exercise info



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Activity Tracking System Components

Sensor Data Collection
IMU for accel/gyro readings
BLE for transmission

Activity Classification
Stats for feature extraction
ML model for classification

Weight Readings
Velostat for pressure reading
Microcontroller for reading values
SciPy for fitting weights

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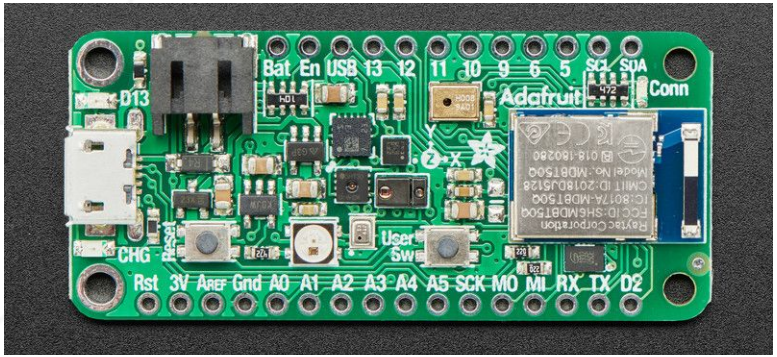
Sensor Data Collection

- You press a button for starting + stopping IMU data transmission for each set



IMU/Microcontroller attached to barbell + turned on

	timestamp	accel_x	accel_y	accel_z	gyro_x	gyro_y	gyro_z
0	483292	-0.487	-0.382	10.006	0.156	-0.081	-0.035
1	483296	-0.487	-0.382	10.006	0.156	-0.081	-0.035
2	483300	-0.487	-0.382	10.006	0.156	-0.081	-0.035
3	483303	-0.471	-0.383	10.004	0.154	-0.084	-0.035
4	483325	-0.434	-0.361	10.025	0.148	-0.088	-0.038

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Yes, we actually collected data at the CRC

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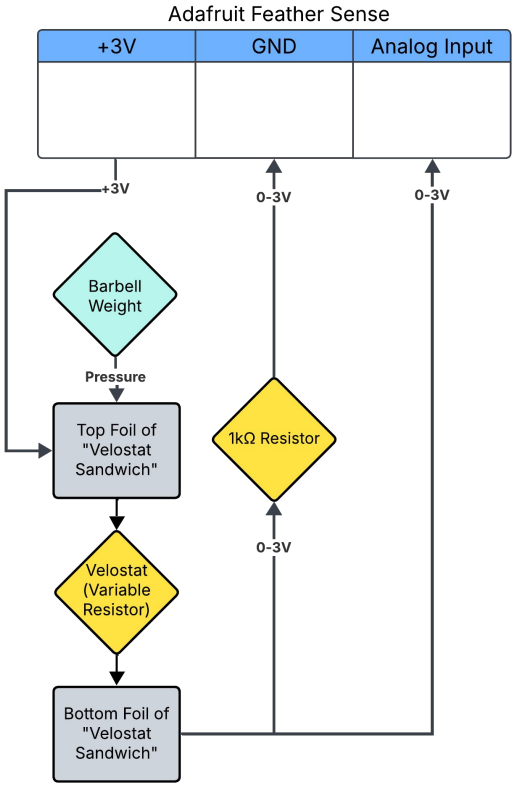
Velostat Platform

- Research Question: Can we systematically detect how much weight was added to a barbell in a seamless manner?
- Solution: Create an electrical “voltage divider” circuit, with Velostat acting as a variable resistor, to infer pressure/weight applied to Velostat.
- Higher pressure from weight
  = Higher compression of Velostat
  = Lower resistance from Velostat
  = Higher Analog-to-Digital (ADC) reading



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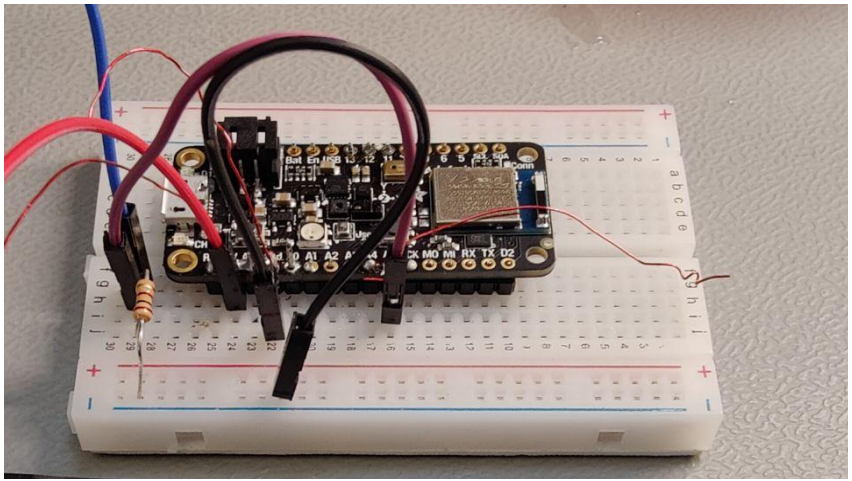
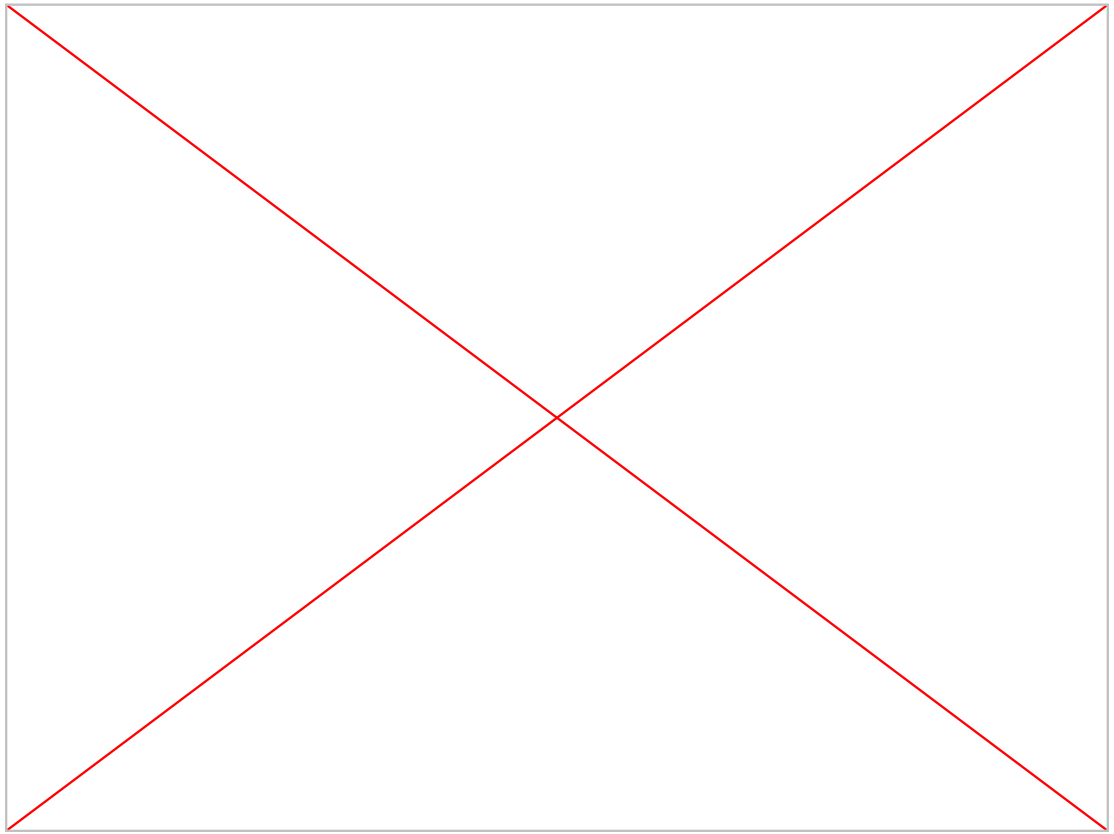
Velostat Platform

- With these ADC readings, how do we determine what reading corresponds to what weights?
- Solution: Use baseline measurements to fit our data to a polynomial function via SciPy's `curve_fit` function, producing the optimal parameters for our data
- We can use the produced parameters in the Feather's microcontroller loop for on-line weight estimation.



Velostat Data Collection (2.5 lbs)



A Better look at our results

```
1,1069127,235425,2.500,
1,1069131,235425,2.500,
1,1069158,235425,2.500,
1,1069162,235425,2.500,
1,1069188,235425,2.500,
1,1069192,235425,2.500,
```

2.5 lbs

```
1,1206311,235425,5.000,
1,1206315,235425,5.000,
1,1206319,235425,5.000,
1,1206340,235425,5.000,
1,1206344,235425,5.000,
1,1206402,235425,5.000,
```

5 lbs

```
1,1402457,235425,10.000,
1,1402508,235425,10.000,
1,1402511,235425,10.000,
1,1402515,235425,10.000,
1,1402538,235425,10.000,
1,1402541,235425,10.000,
```

10 lbs

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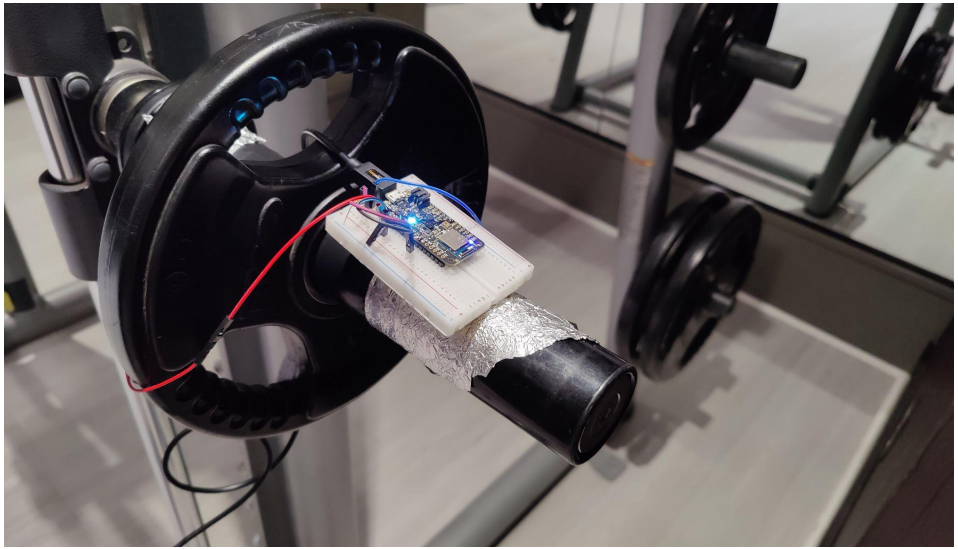
Velostat Platform

- We planned to attach the setup to the barbell itself to measure just the weight.
- Unfortunately, this posed several issues for us



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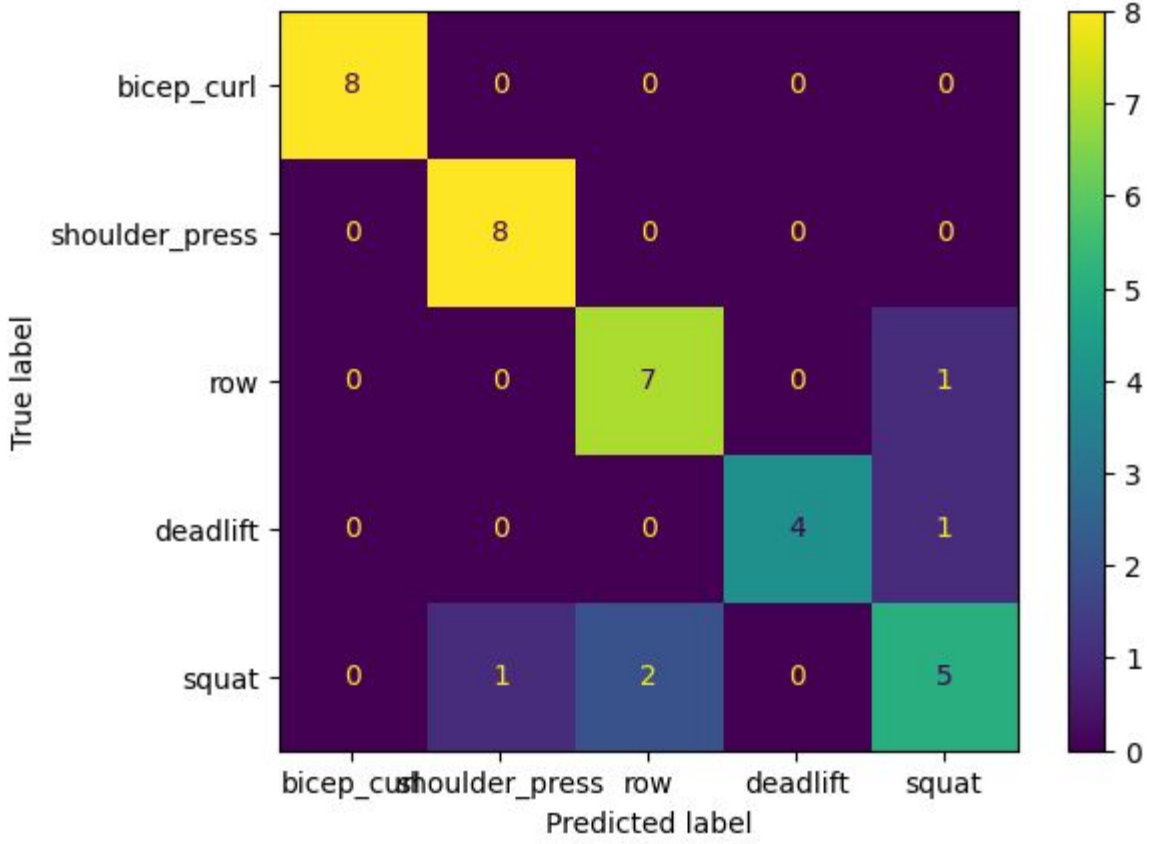
Data Collection

- Collected 2 sets of IMU data for 8 participants on 5 exercises with 8-12 reps
  - Bicep curls
  - Shoulder press
  - Rows
  - Romanian Deadlifts
  - Squats
- Each set formed a dataframe
  - First set used for training ML classification model
  - Second set for testing
- Extracted features from each dataframe
  - Duration, Mean of each column, Std, 10^{th}, 25^{th}, 75^{th}, 90^{th} Percentiles, Root median squared error, Energy in FFT frequency bands (low, medium, high)
- Used features to predict activity label with Random Forest Classifier

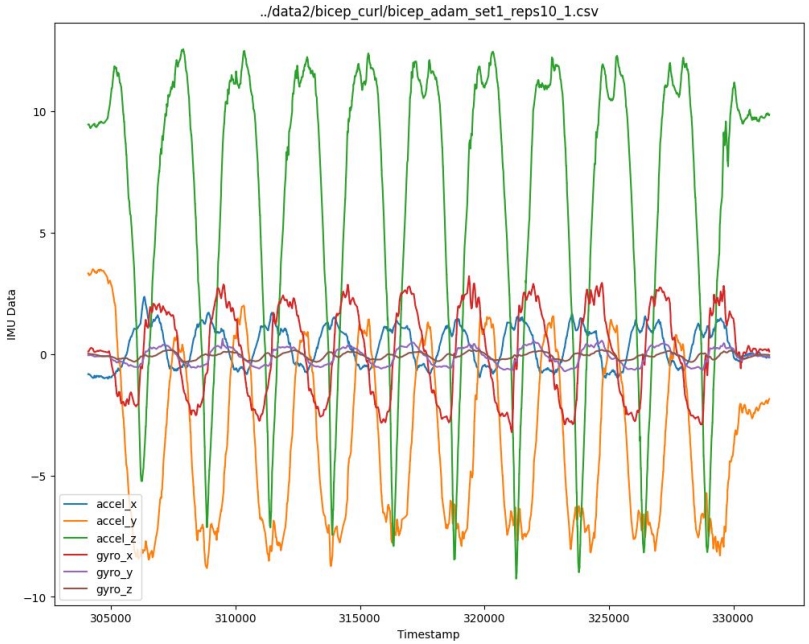
Classification Results

- 87% accuracy
- Less successful at classifying lower body exercises
  - Consistent with other lit



Alternative Approach to Classification

- Feed the dataset into deep learning (DL) models after resampling to n points
  - Single models: CNN, LSTM, …
  - Ensemble of DL models
- Add additional features
  - Acc./Gyro. Mag, Acc. Jerk, zero crossings
- Use SciPy's `find_peaks` to segment
- Best models had 80-83% accuracy, but training took longer and results were inconsistent
  - Random validation sets
- Other papers using ML with time segmentation got 80-90% accuracy



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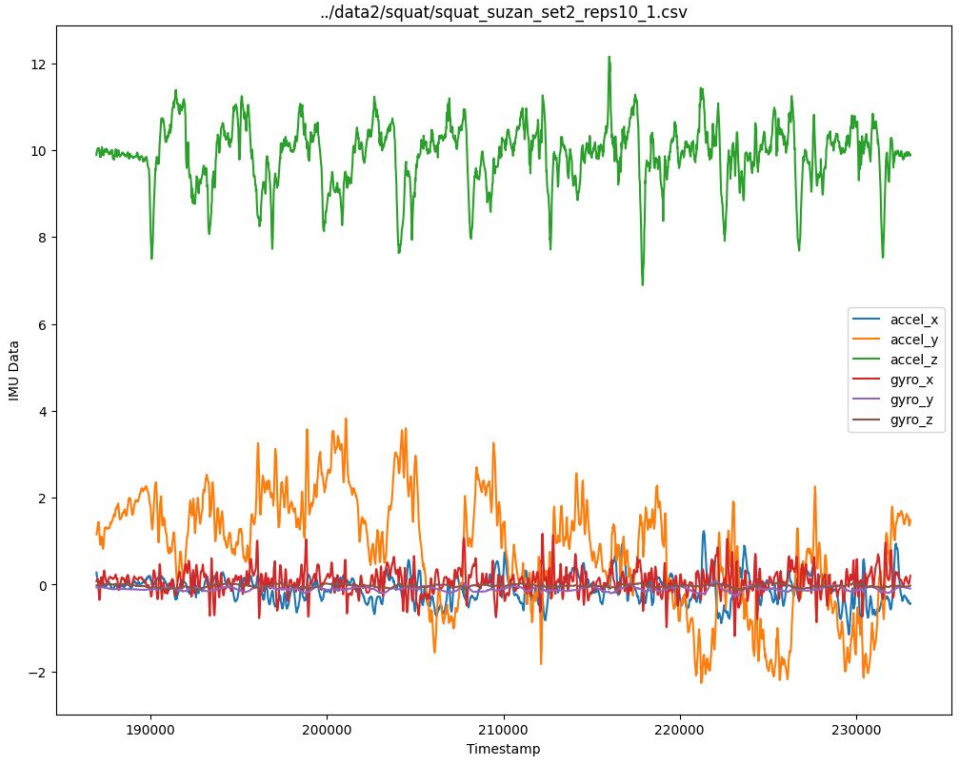
Rep Counting

- Counted reps through SciPy's peak/valley counting feature `find_peaks`
- Not all our data looked like clear sin curves + reps take different times, so this failed for messy data
- 15% accuracy



Limitations

Exercise Classification

- Limited data collection
- IMU randomly turns off + on again leading to data loss
- The only equipment we track activity for is barbells
    - Attaching IMU to wrist/legs would allow for more generalization, but then it's only a personal solution

Weight Estimation

- Velostat reading tends to drift upwards over time, creating instability.
- Velostat readings fluctuate based upon where weight is placed.
- If setup is placed on the bar itself:
    - Barbell rotation would lead to fluctuating values
    - Velostat and foil get damaged when adding/removing weights
    - Sensing setup may not be able to fit within the inner section of the weight
    - The inner section of the weight may be composed of metal, requiring a thicker material on the bar

Future Work

Exercise Classification

- Add weight measurements to feature set to see if this improves accuracy
- Collect more data for training + testing
- Try to classify more exercises
- Improve rep counting
- Exercise form assessment from sensors
    - Requires exercise science/personal training expertise

Weight Estimation

- Incorporate/verify robustness with multiple weights on each side
- Testing this type of system against extremely heavy weight configurations
- Identify a method to place velostat setup on barbell itself

Successes

✅ Successfully classified upper-body barbell exercises w/ ML

✅ Fine-grained weight tracking (+/- 2.5 lbs) w/ Velostat

✅ All-in-one system for data collection & classification

Questions?

https://github.com/suzm10/wireless-imu-activity-tracking

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Appendix

Velostat Data Collection (5 lbs)

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Velostat Data Collection (10 lbs)

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