Lab 3: Double Pendulum

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Pendulum Calibration

Lower Pendulum

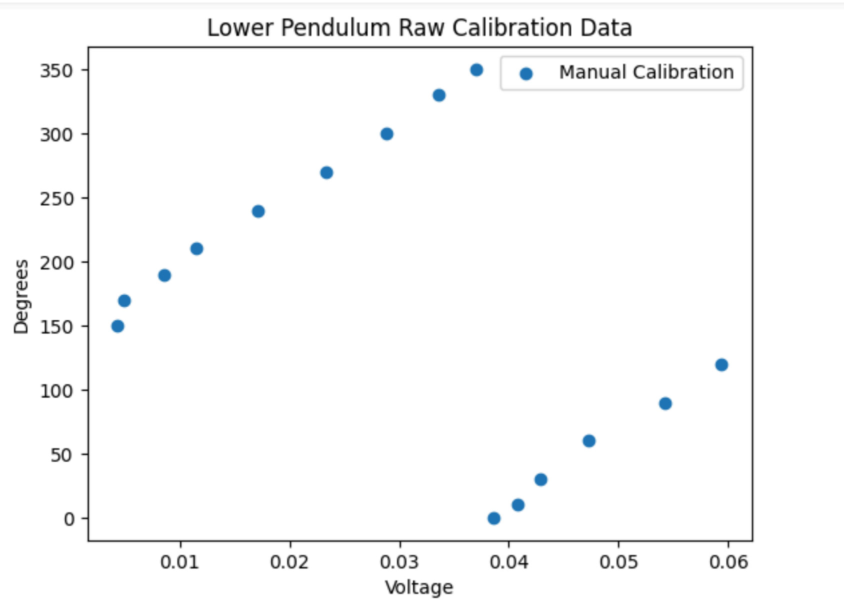

Figure 1. Lower Pendulum Raw Calibration Data

The raw calibration data shown in fig. 1 for the lower pendulum revealed a noticeable voltage discontinuity at approximately 0.036 seconds, indicating a calibration jump. To address this, we applied an offset to the average voltage at this point. And used the new offset to create a linear fit for our data as shown in fig. 2. In retrospect, identifying this jump as the zero-degree reference point would have ensured continuous data and improved the accuracy of our initial angle measurements. This oversight affected the initial conditions used in our experiments.

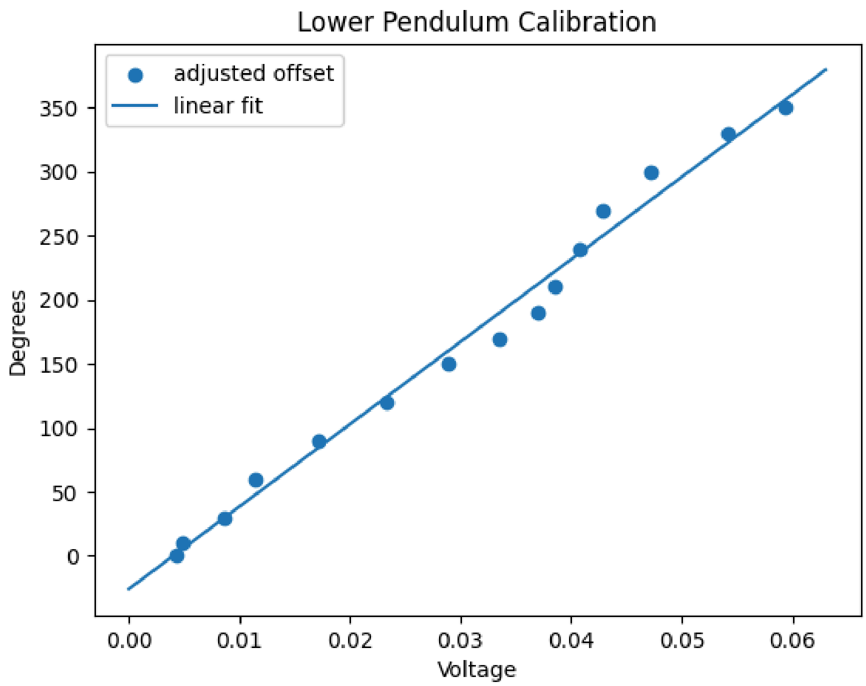

Figure 2. Lower Pendulum Linear Fit

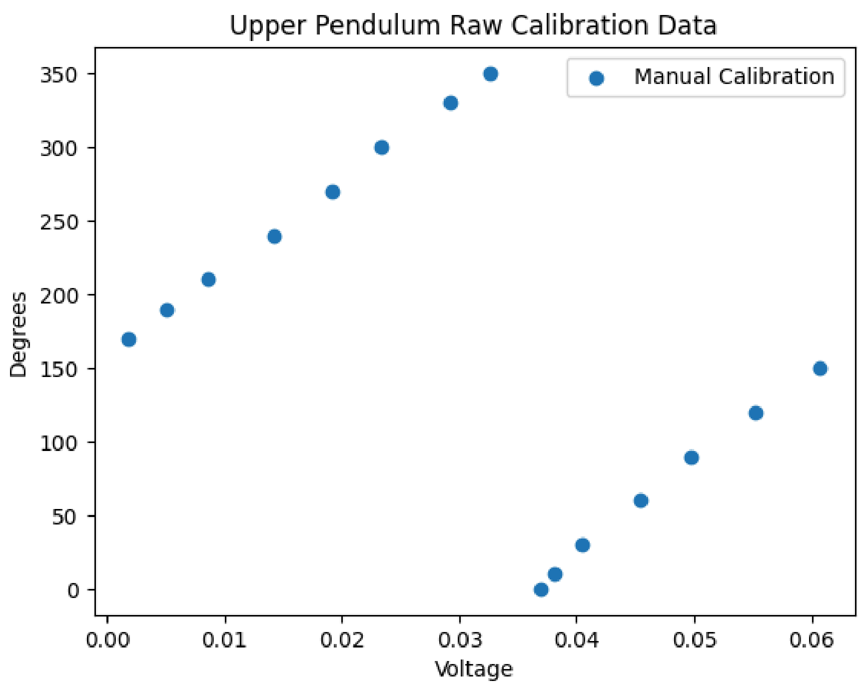

Figure 3. Upper Pendulum Raw Calibration Data

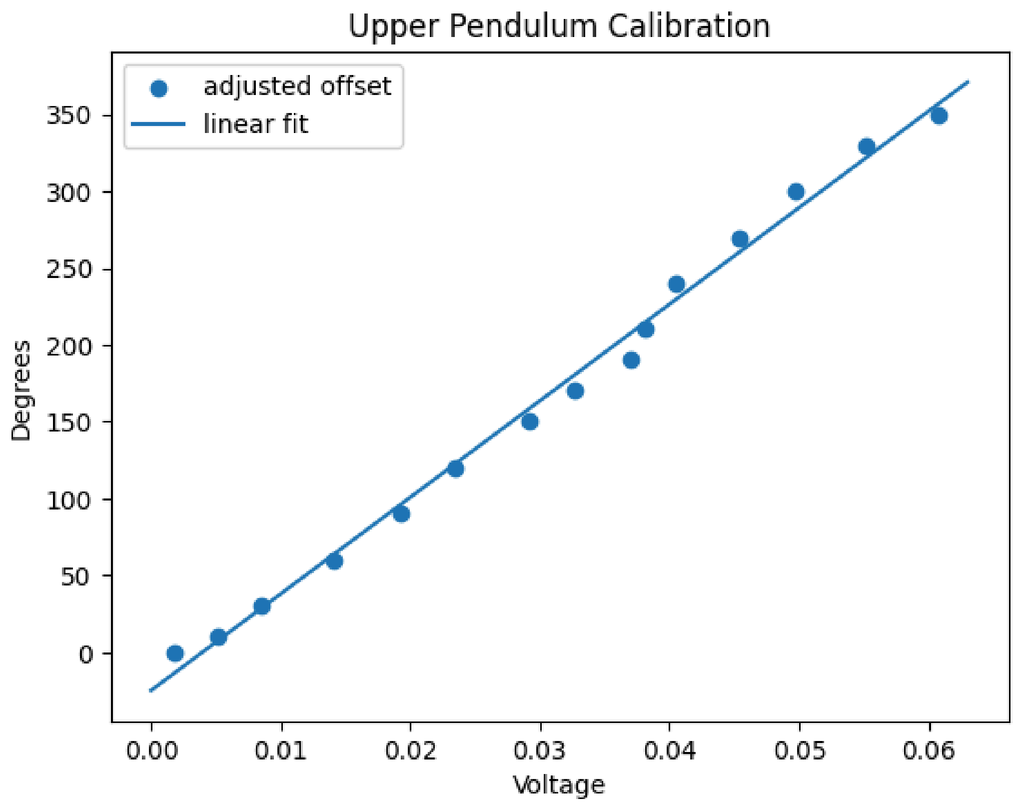

Figure 4. Upper Pendulum Calibration Linear Fit

Similarly, the upper pendulum calibration (fig.3) exhibited a voltage offset around 0.037 volts, corresponding to an angle of approximately 170 degrees. We mitigated this by applying the same voltage offset correction used for the lower pendulum, aiming to align the data consistently. The linear fit is shown in fig. 3.

Repeatability Experiment

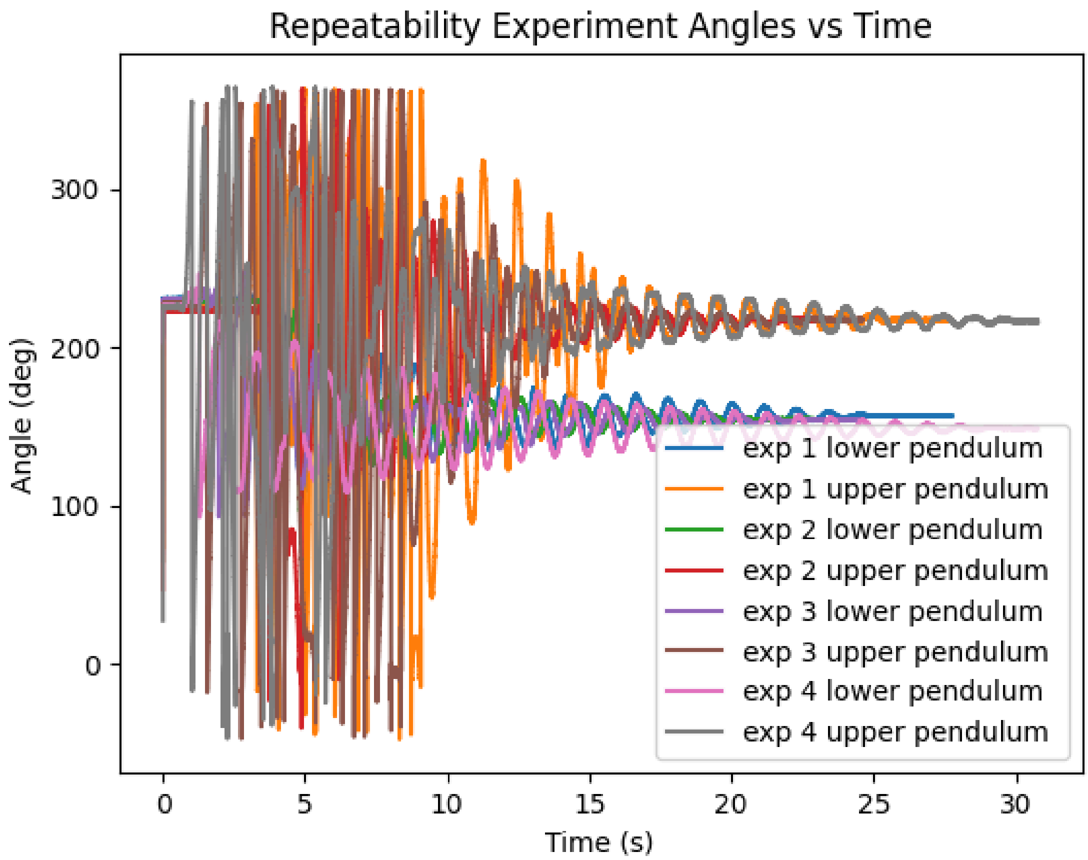

Figure 5. Repeatability Experiment Angles vs Time Plot

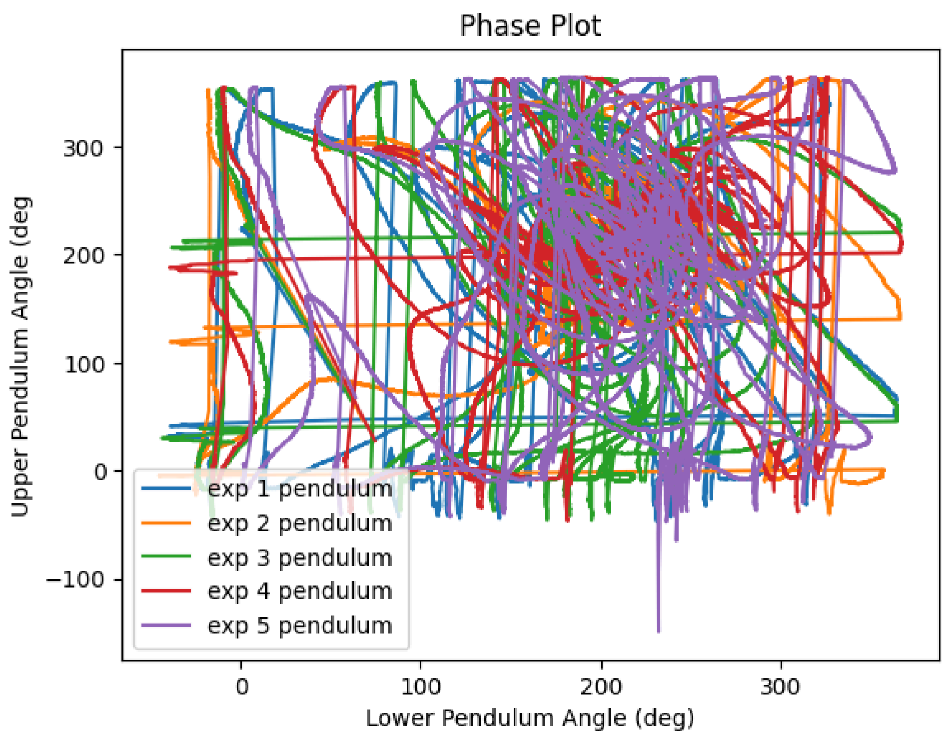

Figure 6. Repeatability Phase Plot

Five experimental runs were conducted with the same initial conditions to assess repeatability. The time series data (fig. 5) for both the upper and lower pendulums across five runs showed consistent patterns, though slight variations were evident due to the system's sensitivity. Corresponding phase plots (fig. 6), mapping angles against time. This plot showed random movement of the two pendulums and none of them seemed to be consistent with each other, further emphasizing the unrepeatability of our runs.

Predictability Experiment

	experiment	trial	upper_cw	upper_ccw	lower_cw	lower_ccw
0	1	1	0	0	1	1
1	1	2	0	0	1	7
2	1	3	0	0	6	6
3	2	1	0	0	0	3
4	2	2	0	0	7	2
5	2	3	0	0	6	2
6	3	1	0	0	3	0
7	3	2	0	0	3	0
8	3	3	0	0	10	0

Figure 7. Predictability Results Table

Fig. 7 above shows a summary of pendulum rotations. There were no full rotations for the upper pendulum, consistent with experimental observations, while the lower pendulum exhibited both clockwise and counterclockwise rotations. For the same initial condition, we could not replicate the same number of counts.

Angular Velocity

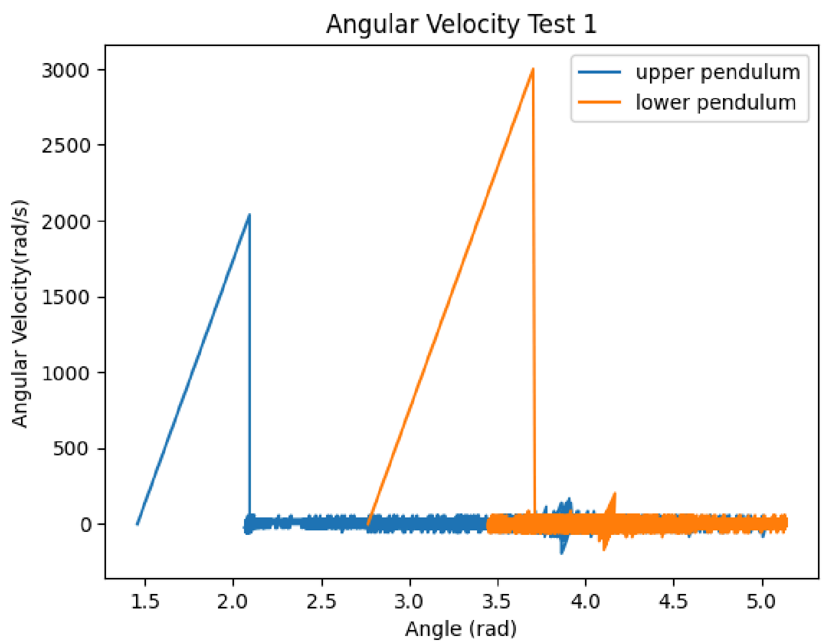

Figure 8. Angular Velocity Test 1 Plot

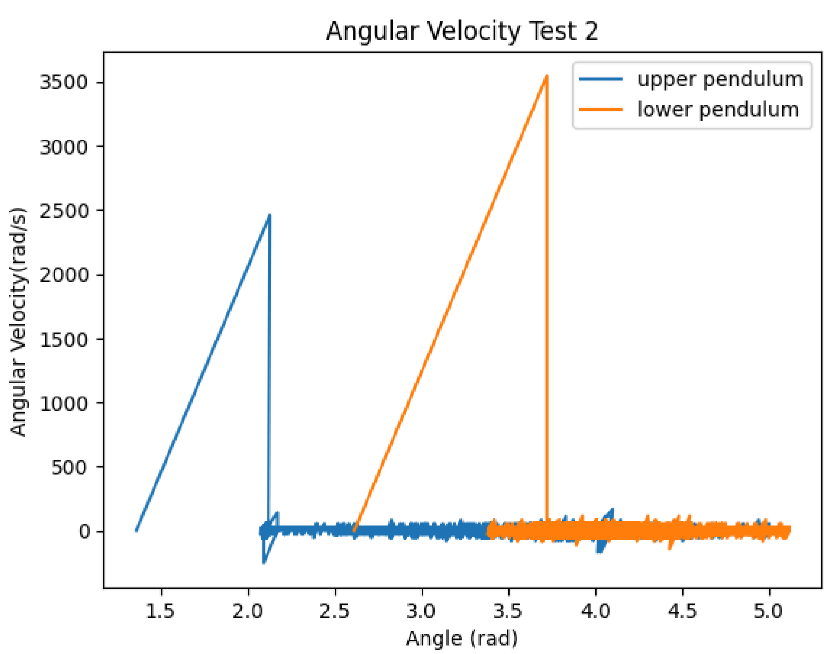

Figure 9. Angular Velocity Test 2 Plot

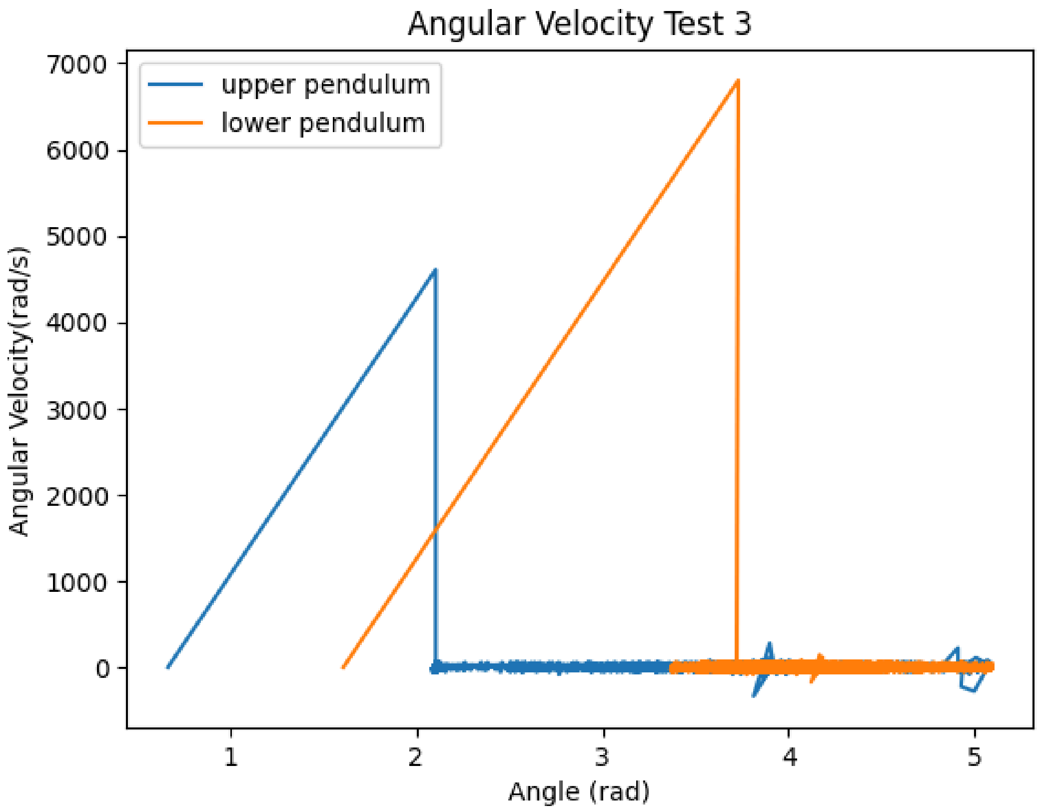

Figure 10. Angular Velocity Test 3 Plot

The angular velocity versus angle phase plots (fig. 8- fig. 10) revealed a significant jump at the point of initial release, likely due to high initial acceleration. This large initial velocity spike overshadowed the lower pendulum's angular velocity variations, making it challenging to distinguish trajectory differences in the phase plots. The jump suggests that our initial condition measurements or release mechanism introduced inconsistencies.

Numerical Simulation

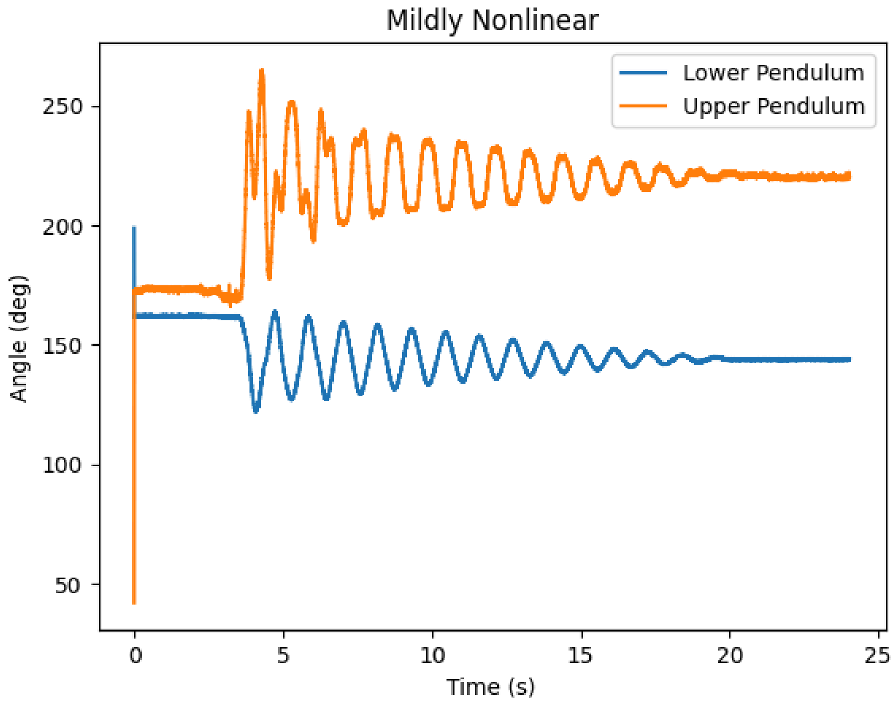

Figure 11. Mildly Nonlinear Raw Data Plot

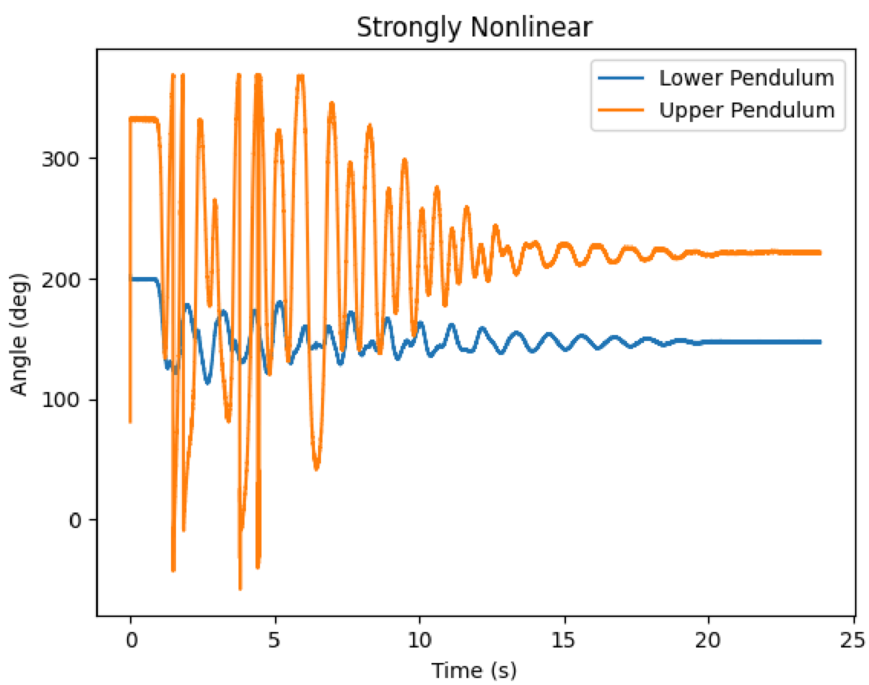

Figure 12. Strongly Nonlinear Raw Data Plot

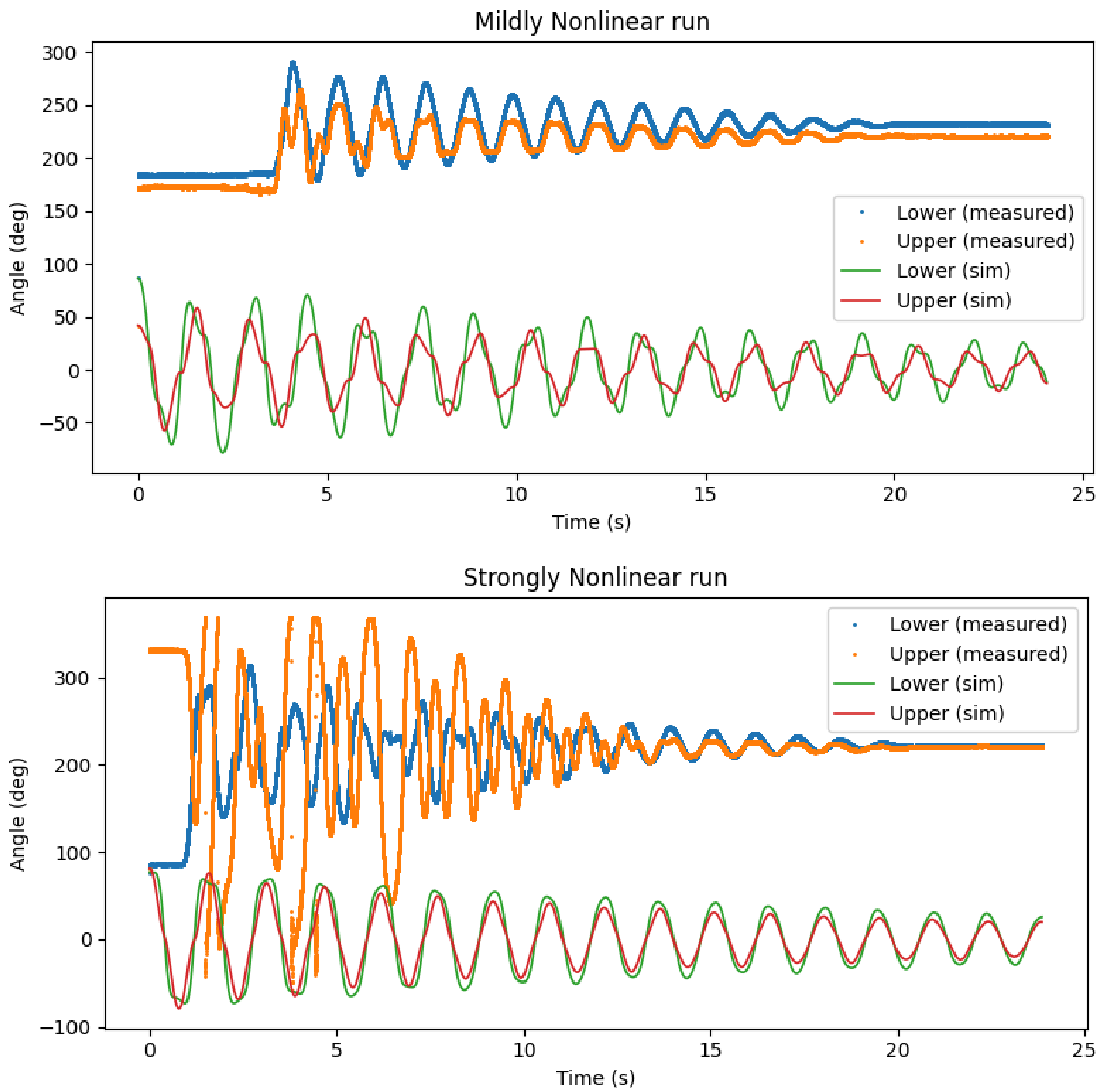

Figure 13. Numerical SImulation Plot vs Measured Run

Comparing numerical simulations (fig. 13) to experimental data proved difficult. Adjusting the friction coefficient to match observed damping was problematic: the simulated damping was either too rapid or insufficient, failing to capture the system's nonlinear behavior accurately. This discrepancy highlights the complexity of modeling the double pendulum's chaotic dynamics.

Conclusion

Across our experiments spanning repeatability, predictability, angular velocity analysis, and numerical simulations we observed significant challenges in replicating experimental results. These difficulties likely stem from the double pendulum's inherent nonlinearity, compounded by minor inaccuracies in setting initial conditions. Small variations in initial angles, exacerbated by calibration offsets, led to divergent outcomes in each run. These findings underscore the sensitivity of chaotic systems and the importance of precise initial condition measurements for accurate modeling and prediction.