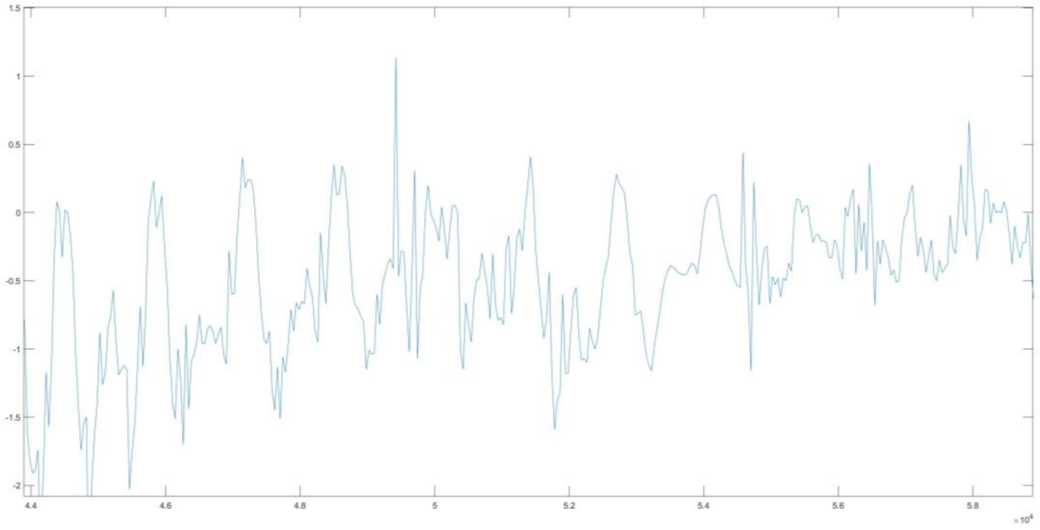
Finding Chaos During a Pandemic: Studying Pendulum Motion



- **Sara Earnest**, *mentored by*

Professor D. Lathrop, Ph.D.
UMD Nonlinear Dynamics Lab

The Internship's Structure

- I was one of five high school researchers chosen to intern in Dr. Lathrop's Nonlinear Dynamics Lab this summer.
- The internships began in June, however, because of the pandemic all meetings were over zoom.
- Chaos is a part of nonlinear dynamics, which Dr. Lathrop's lab studies mainly using a scale model of Earth's core called the "3-meter experiment".

What is chaos theory? Why do we care?

What is Chaos?

- states of dynamical systems with apparent randomness
- actually governed by deterministic laws

And Chaotic Motion?

- behavior so unpredictable it appears random

Why do we care?

- In fields of robotics and engineering, understanding chaos theory allows for devising predictive models for machine learning, instead of relying on trial and error learning systems.

My Project: Overview

- To construct a magnetized pendulum (the magnetization making the system nonlinear), record and graph its swings, and find pockets of chaotic motion
  - The pendulum was equipped with two Arduinos
- One I programed to run a linear servo motor at the top of the pendulum to it in motion and combat friction; and a second I programed to collect data from each swing.
- I graphed the data collected through the Arduino (using Matlab), I then analyzed it for chaos.

Research Timeline

JUNE

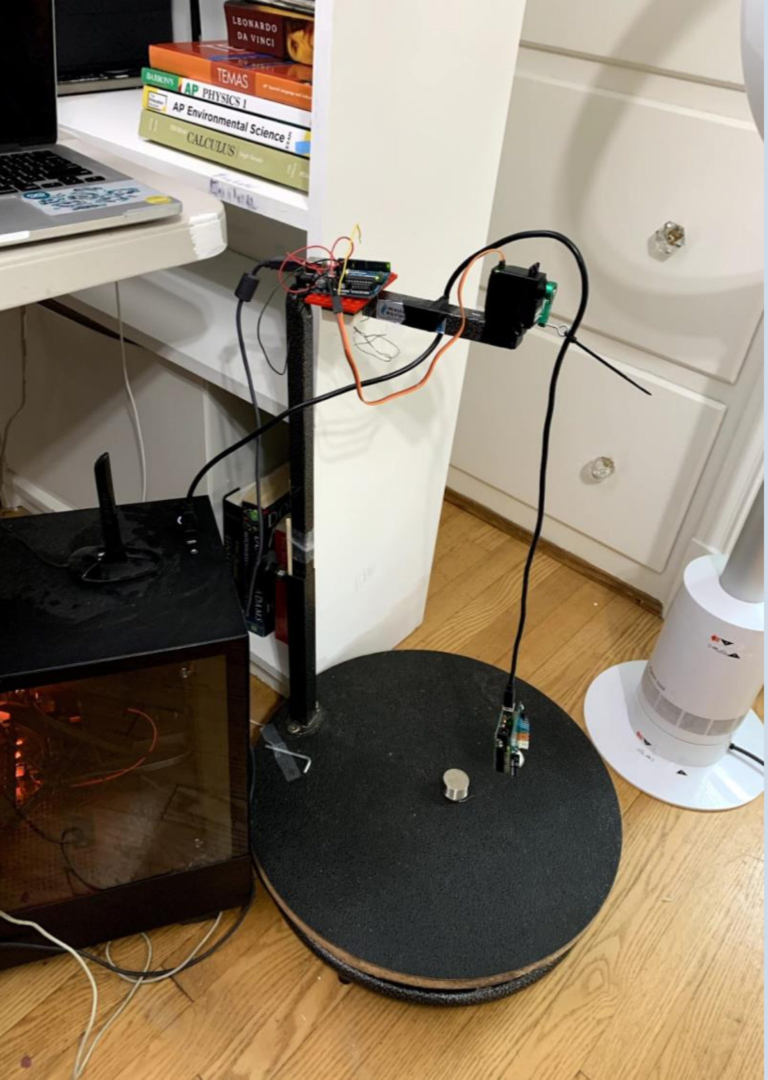
- constructed basic pendulum design (no magnets)
- Started on python code to extract data
- bought and programmed arduinos

JULY

- replaced python code with RealTerm (program to extract data for you)
- constructed a forcing with a servo motor to combat friction
- ran test trials of the pendulum without chaos
- plotted all data in matlab

AUGUST

- switched out current servo motor for a better one. changed design slightly
- added the magnets to the system, making it chaotic
- collected data of the now-chaotic pendulum and plotted it with MatLab
- Identified chaotic motion within data

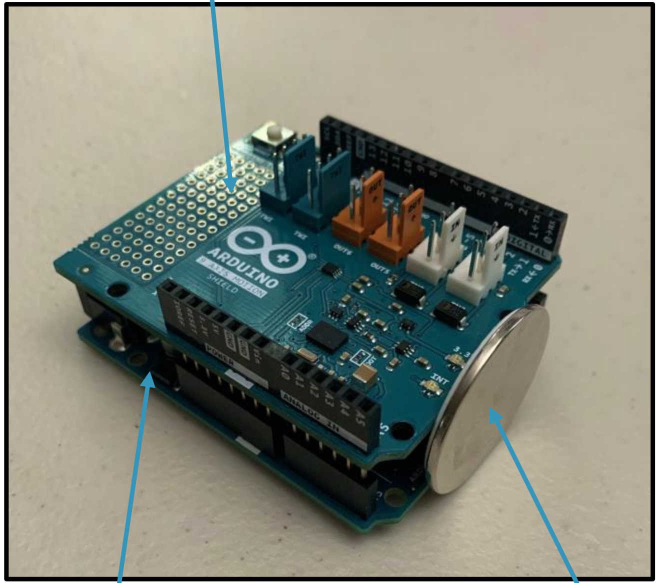


Constructing the Pendulum

- Using home supplies, I constructed my pendulum from my dog's grooming stand.
- I placed one strong magnet atop the pendulum and a repelling magnet directly below.
- I used Legos and electrical tape to attach the Arduino and servo motor to the pendulum's top.

Tools and Terms: Arduino

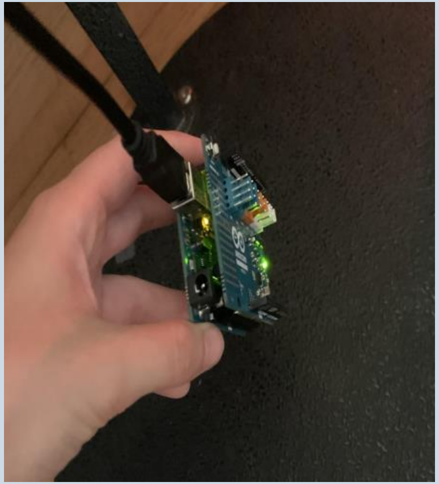
- Two components:
  - hardware constituting a programmable microcontroller (circuit board)
  - Software: IDE (Integrated Development Environment) on your computer to write and upload code to the physical board
- One Arduino was placed atop the pendulum and programed to run the linear servo motor in order to keep the pendulum in motion.
- A second Arduino with motion shield was the weight of the pendulum and recorded data from its motion



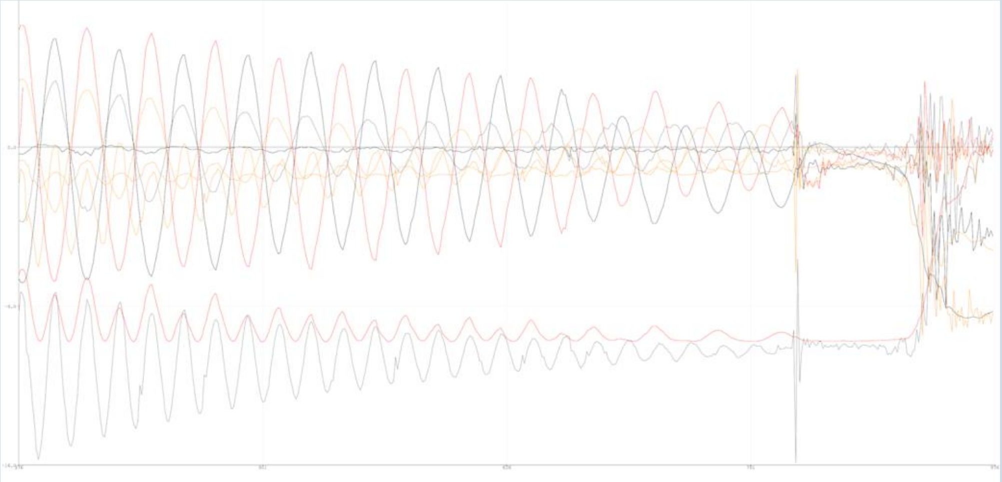
In the Beginning

- The original plan was to first construct a simple pendulum with an arduino and 9-axes sensor shield as the weight.
    - I would then write a python code to extract the data so I could analyze it

(left and below) The very first setup– a simple pendulum

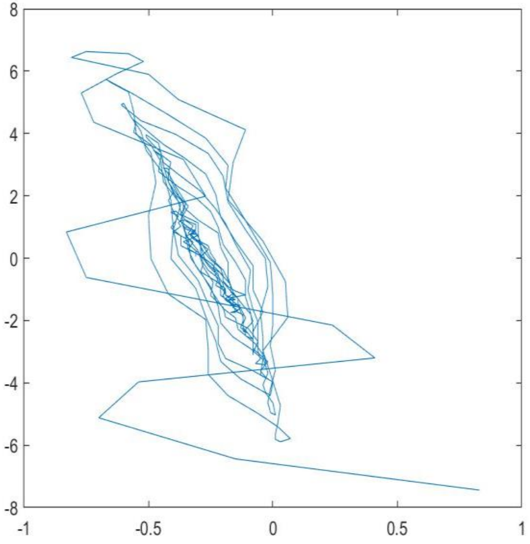


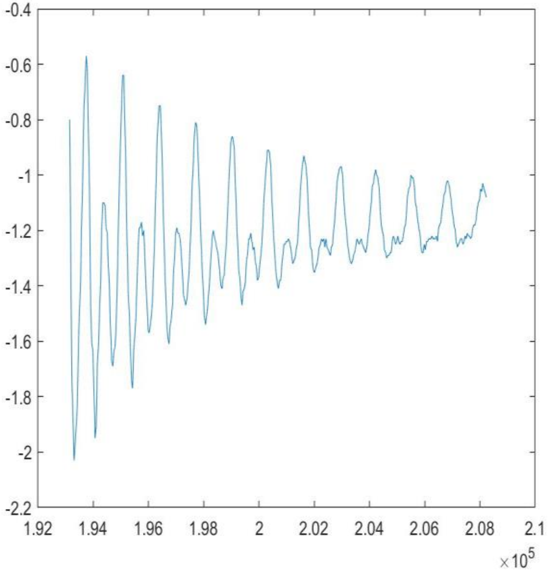
Data taken from the simple pendulum before extraction (taken with the arduino serial plotter)



Midway Through

- I tested the setup by taking data of the simple pendulum swing and plotting it in Matlab

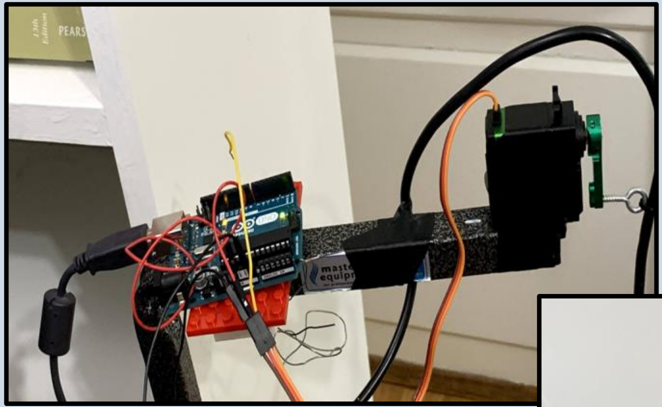


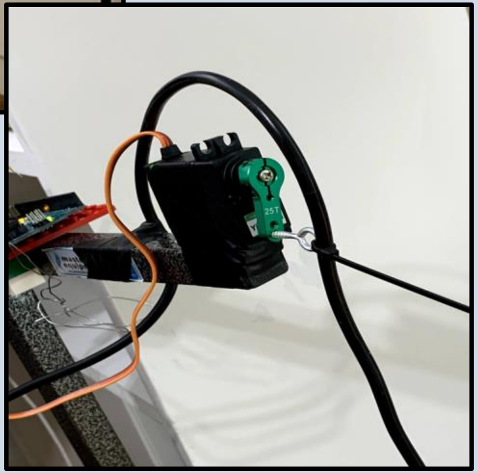


From left to right: Data plotted in Matlab (z-axis acceleration plotted against z-axis gravitational acceleration on left, x-axis acceleration plotted against time on the right.)

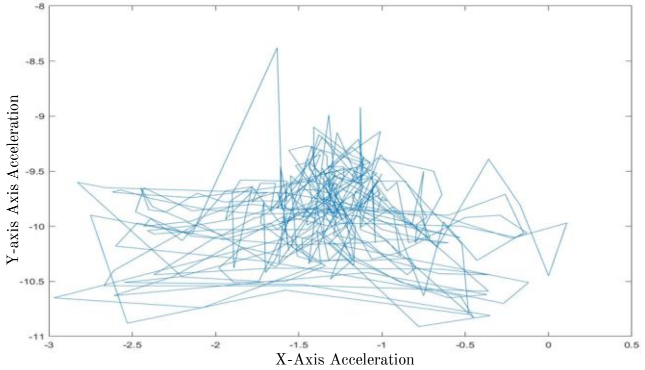
A New Design and the Home Stretch!

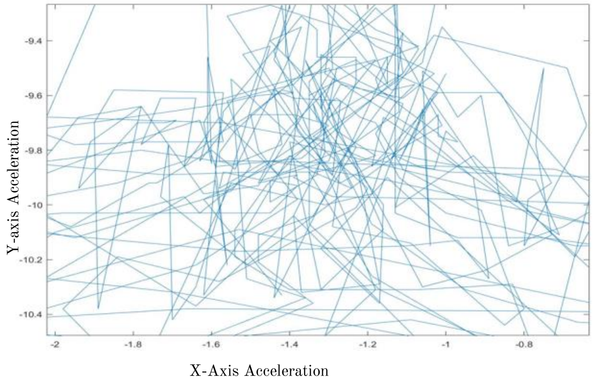
- Magnetized the pendulum in two places, the magnets repelling each other
  - This would be the cause of the chaotic motion
- Added a servo motor to keep the system from decaying due to friction
- Took and plotted graphs with MatLab, looking for chaos



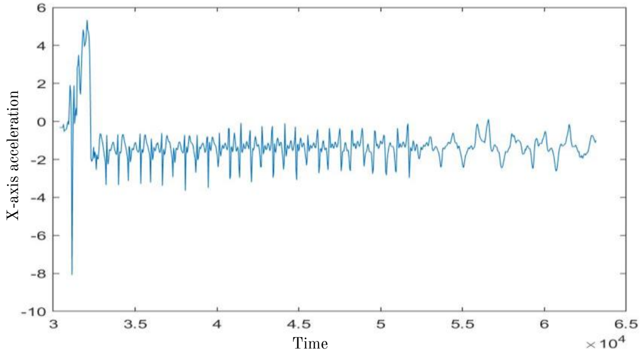


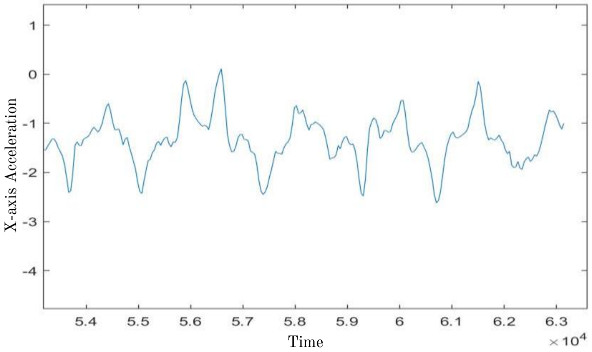
Finding Chaos and Graphing it





Graph of x-axis acceleration versus y-axis acceleration (and closeup), data points 400 through 820





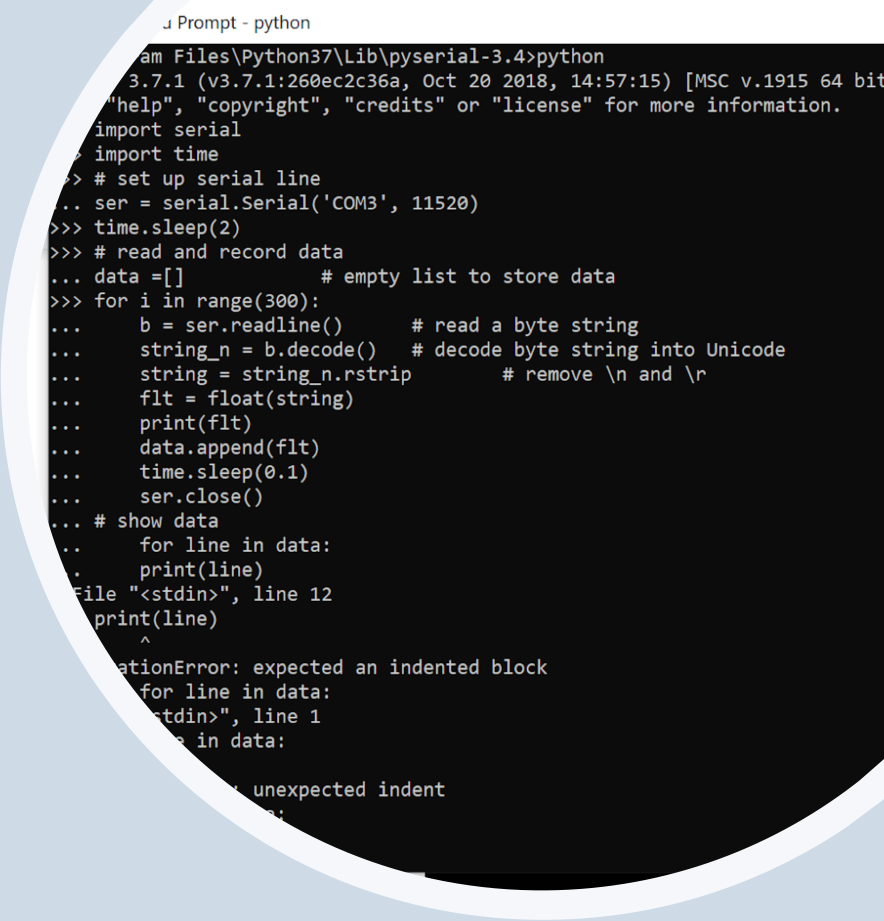
Graph of time versus x-axis acceleration (and closeup)

There Were Challenges:

- Making sure the servo motor drives the pendulum at a constant but low amplitude (timing)
- Getting the servo Arduino and the data collection Arduino to run at the same time out of different ports

I Made Mistakes:

- Intially I wasted time with the Python code, eventually switched to RealTerm
- Struggled with the design when adding in the servo motor/second arduino



(above) my original python code I ended up discarding

Procedures Learned

1. Programming an Arduino
2. Using MatLab to plot graphs and analyze data
3. Recognizing, graphing, and comprehending pockets of chaotic motion in data
4. Mathematical concepts used to detect and record chaotic motion.
5. Engineering research involves a lot of trial and error.
6. Asking for help is essential to successful engineering designs.

Thank you!!