Exploring the Kinematics of Vortex Rings in a Rotating Reference Frame;

Colors, Particles, and Robots

By Tyler Greiner

Overall Objectives of the Research Project

1) Begin understanding the kinematics of vortex rings in our rotating frame of reference
2) Investigate whether or not the creation of a vortex ring results in a mean flow in system

How we take Data

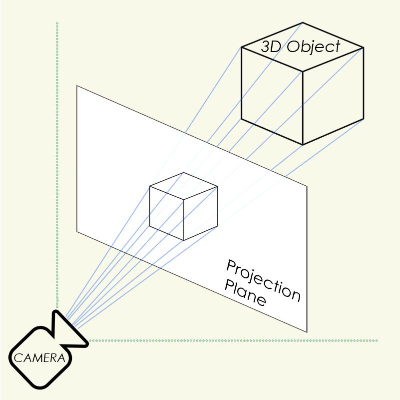
Data is taken through a GoPro Hero 4 camera

The video footage is then taken for analysis on the computer

To process the data, a mixture of python as well as Matlab was used

Understanding What a Video is

1) Our video is a collection of frames
2) Each frame can be seen as a 2D projection of our 3D space
3) This mapping is then made discrete by turning our space into a 1080x1920 pixel grid that each contains 3 numbers describing the color of the location exists



Selecting the best angle to observe

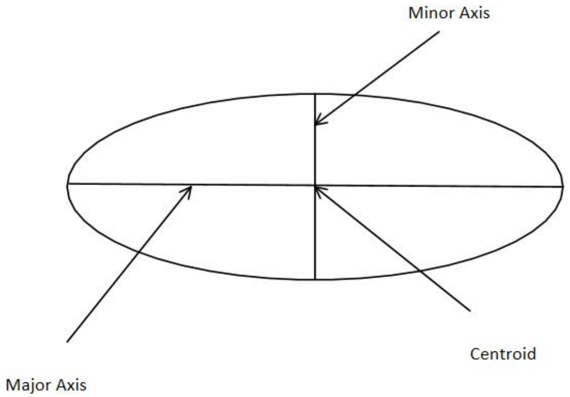
The best angle for a single camera is from the top of the tank

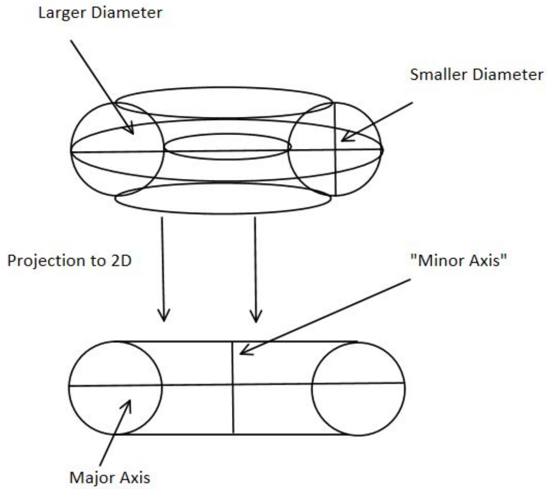
This is the view we would have is the system were 2D (which is used in some of our assumptions)

From the top down view our vortex rings become ellipse-esque shapes

All of the parameters of the ellipse provide us the parameters of a torus

Parameters of a Torus from Ellipse





How to spot a Vortex Ring

In order to program an ellipse tracking program, a basic procedure must be made to teach the computer

First, the vortex ring has a reasonably distinguishable color from the rest of the tank

Second, the vortex ring has a reasonably ellipsoidal shape

Third, the vortex ring follows a relatively* smooth path through the tank

How a Computer Can Spot a Vortex Ring: Artificial Intelligence

The most frequent/effective approach to spotting objects in images is through the use of AI.

AI object recognition is a highly sophisticated and effective tool at recognizing different objects in images and videos

This approach is in use on many phone, where it creates a collection of photos that contain a specific person the AI identified as being the same

How a Computer Can Spot a Vortex Ring: Artificial Intelligence

Artificial Intelligence can take a significant amount of time to train,

Supposing you have the time to train the AI, it still may need many iterations of training before you have a functional system

In reality, were looking at identifying rather simple geometric shapes, so AI is a little advanced for the task.

Basic AI tracking results

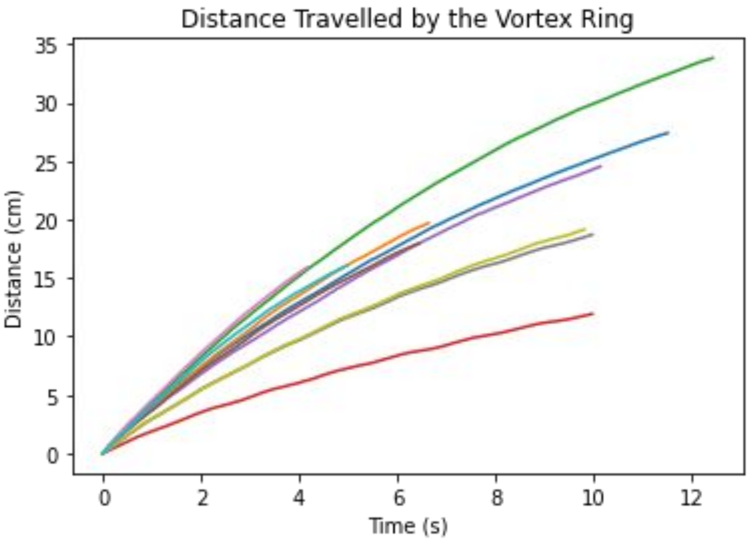
Simplest method we discovered was in an app called Tracker

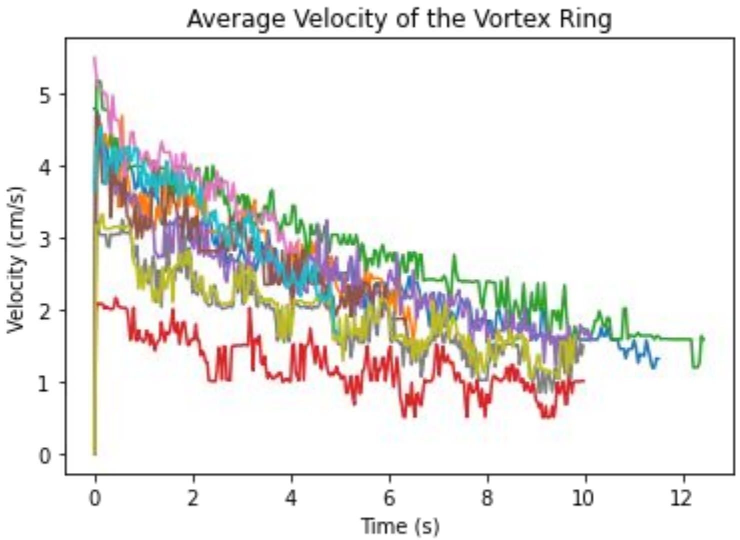
The software had a built in AI that follows an object given at some initial time

This takes a large amount of time to tend to the code

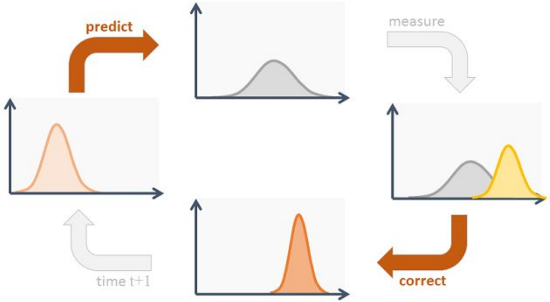
Difficulties with rotating footage

Results from Tracker





How a Computer Can Spot a Vortex Ring: Filters



Another approach that can be taken is through motion detection.

This done by using a subtractive method to find where the pixels are changing, and collecting all of the moving objects.

A Kalman filter is used to separate the moving objects from the minor noise.

This program then provides us with a bounding box where our object lives for each frame in our footage

How a Computer Can Spot a Vortex Ring: Filters

This Filter can be enhanced even further!

As stated before each frame has a collection of pixels containing color data and our vortex rings are a distinguishable color from the tank

So, further noise reduction can be done by removing specific color channels we are not interested in observing

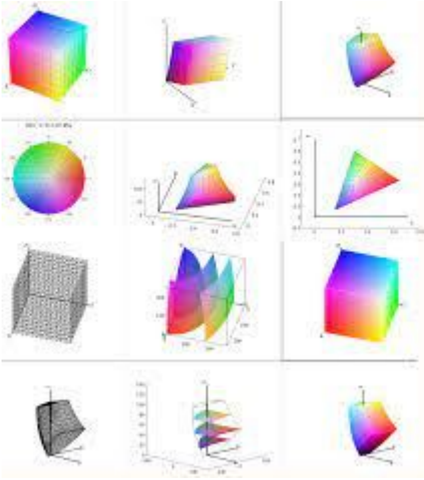
How do we do this?

Color Space

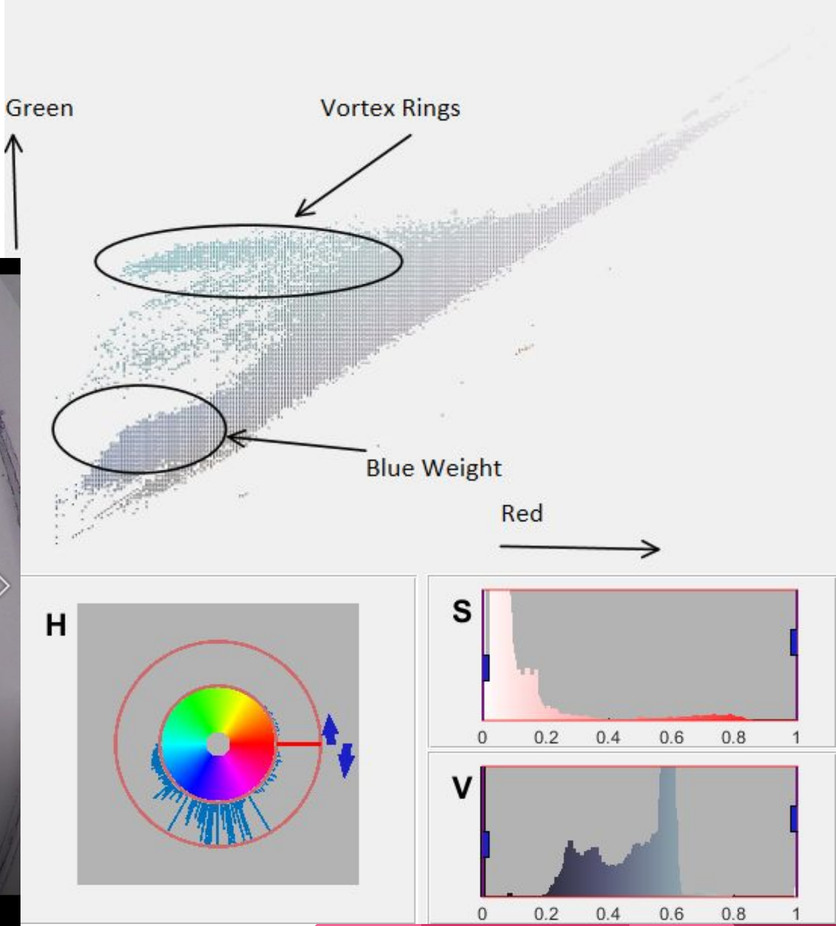
We can define a simplified color space to be a three-dimensional space.

The most well known set of axes for this space are the Red-Green-Blue axes.

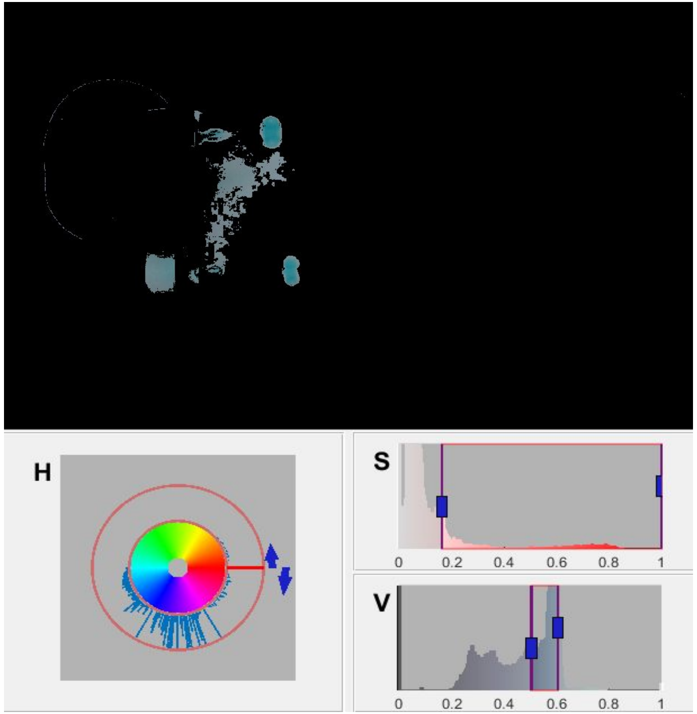
While we dedicated a significant amount of time to trying to make an effective RGB based filter, we discovered another basis described as Hue-Saturation-Value(HSV).



Color Space Visualization

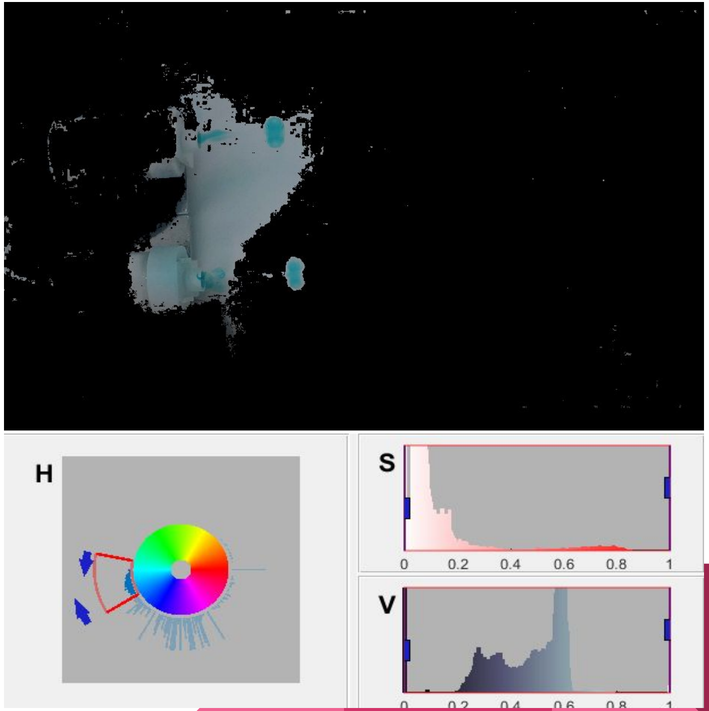


Two Used HSV Filters



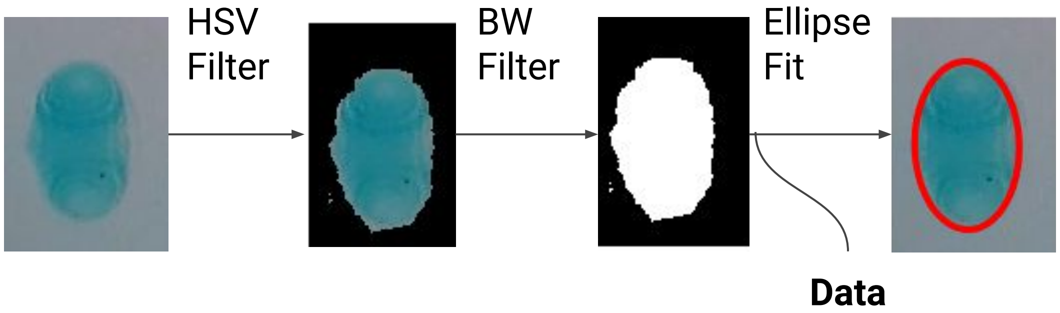
To the left is the filter using an entirely saturation-value filter. This is for tracking

To the Right is the hue filter, which is used for fitting



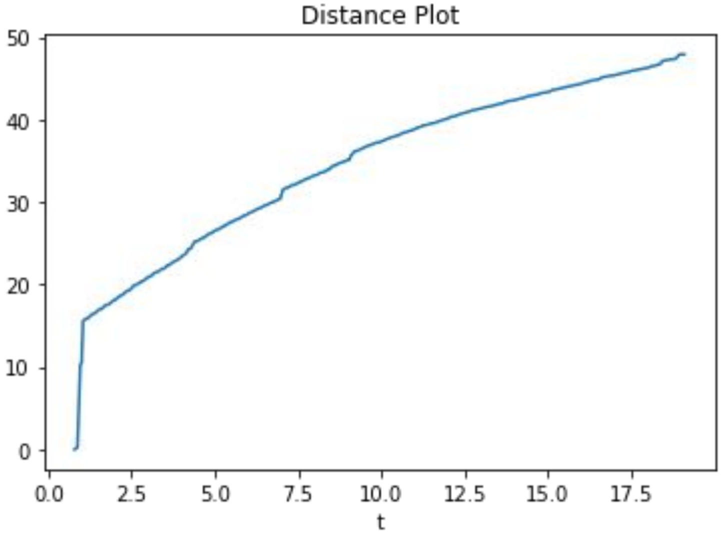
Ellipse fitting

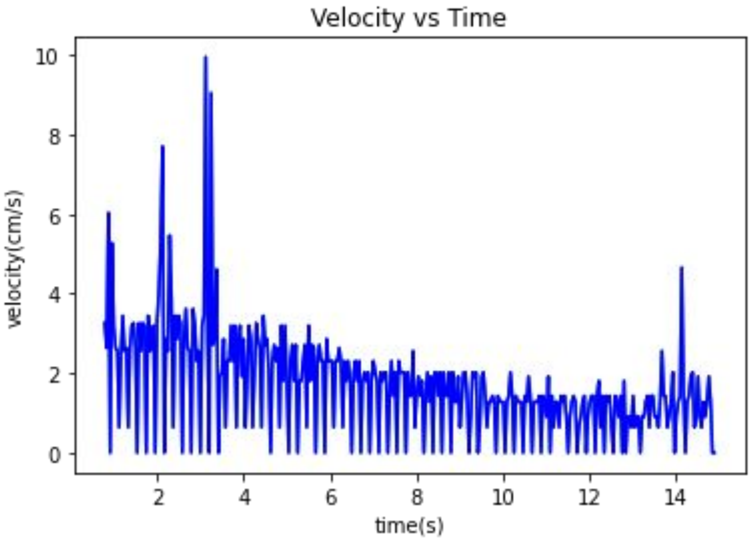
1) Apply a Filter looking at a neighborhood in HSV space
2) Take the remaining pixels and turn them into BW image
3) Hand image over to regionprops, providing us the data needed



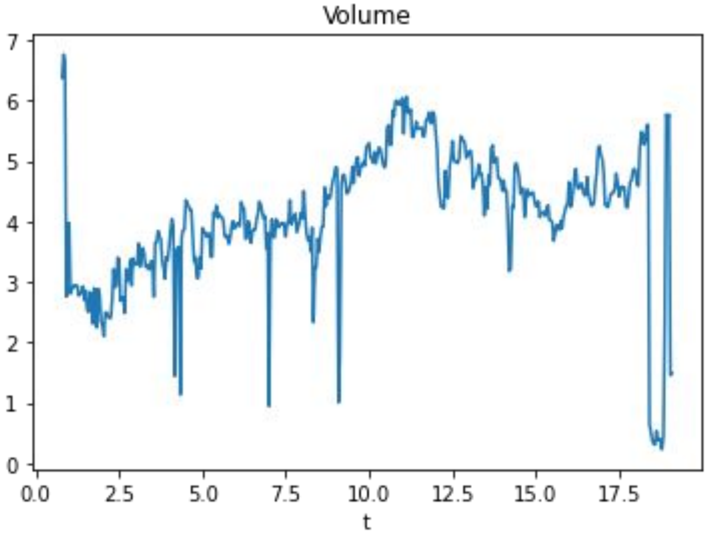
It even works for different orientations!

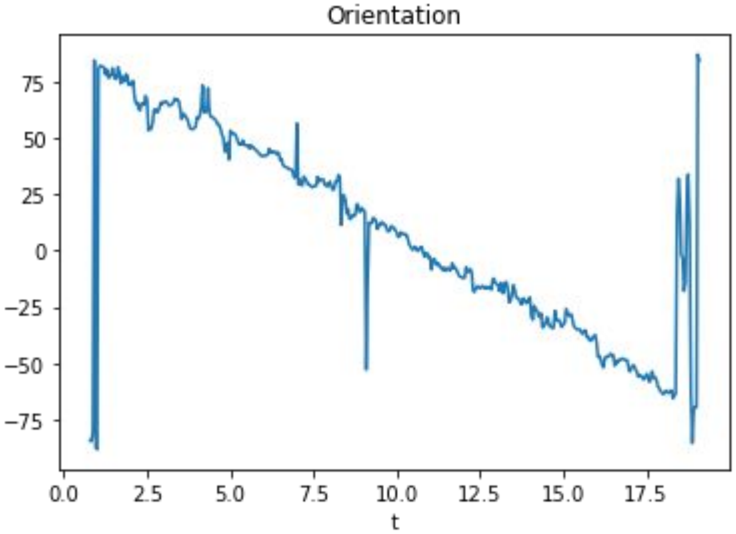
Data from the Ellipse fitting





Data From Ellipse fitting





Kinematic model for the basic vortex ring

Linear drag model:

$$\frac{du}{dt} = \alpha u \Rightarrow u = u_0 e^{\alpha t}$$

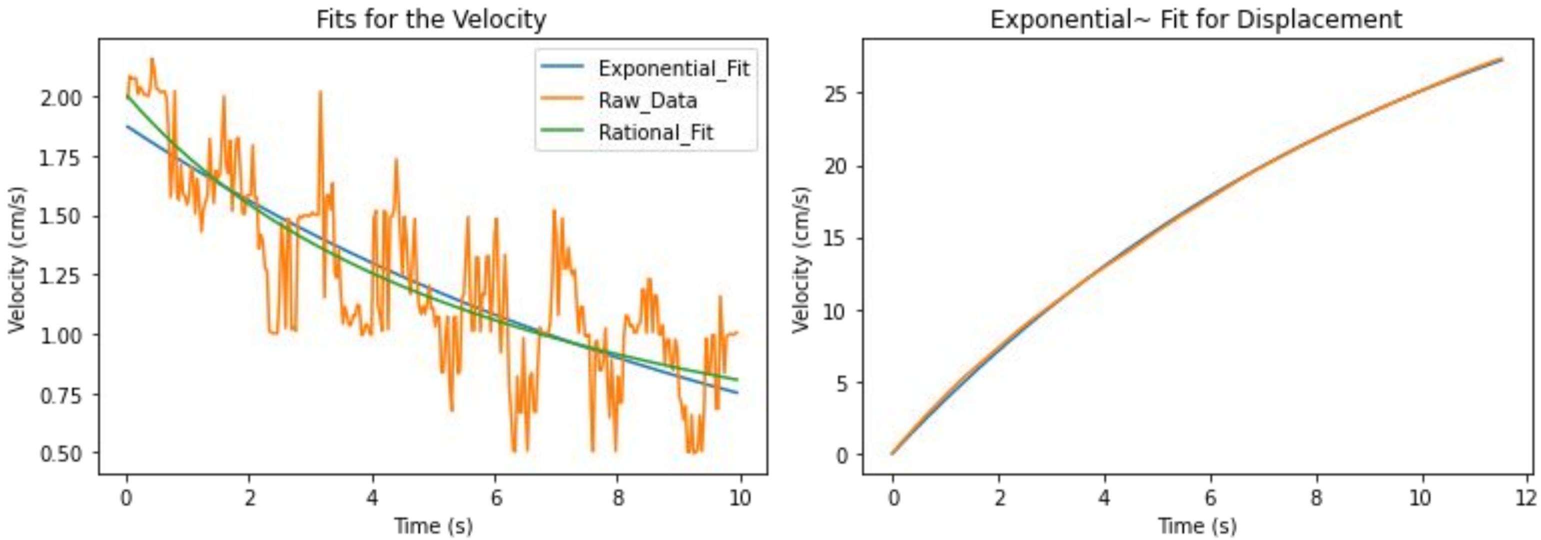
Redefine the Coefficient to be decay time

$$\alpha = \frac{-1}{\tau}$$

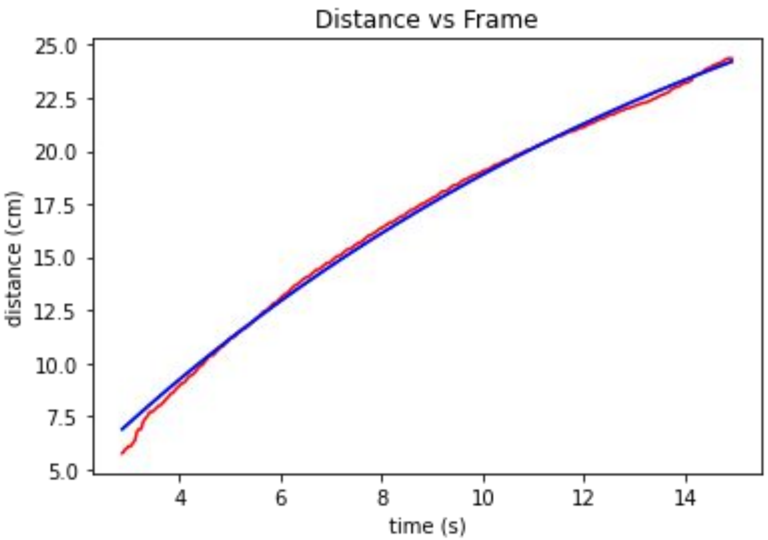
Turn the model into displacement

$$u = u_0 e^{\frac{-t}{\tau}} \Rightarrow s = u_0(1 - \tau e^{\frac{-t}{\tau}})$$

Fitting the Model



Fits on the Ellipse Method



Mean Flow

The mean flow of a system is the average velocity of the system in question.

The holy grail of the research project would be to measure a mean flow in the east-west direction, induced from the launching of a vortex ring in the up direction.

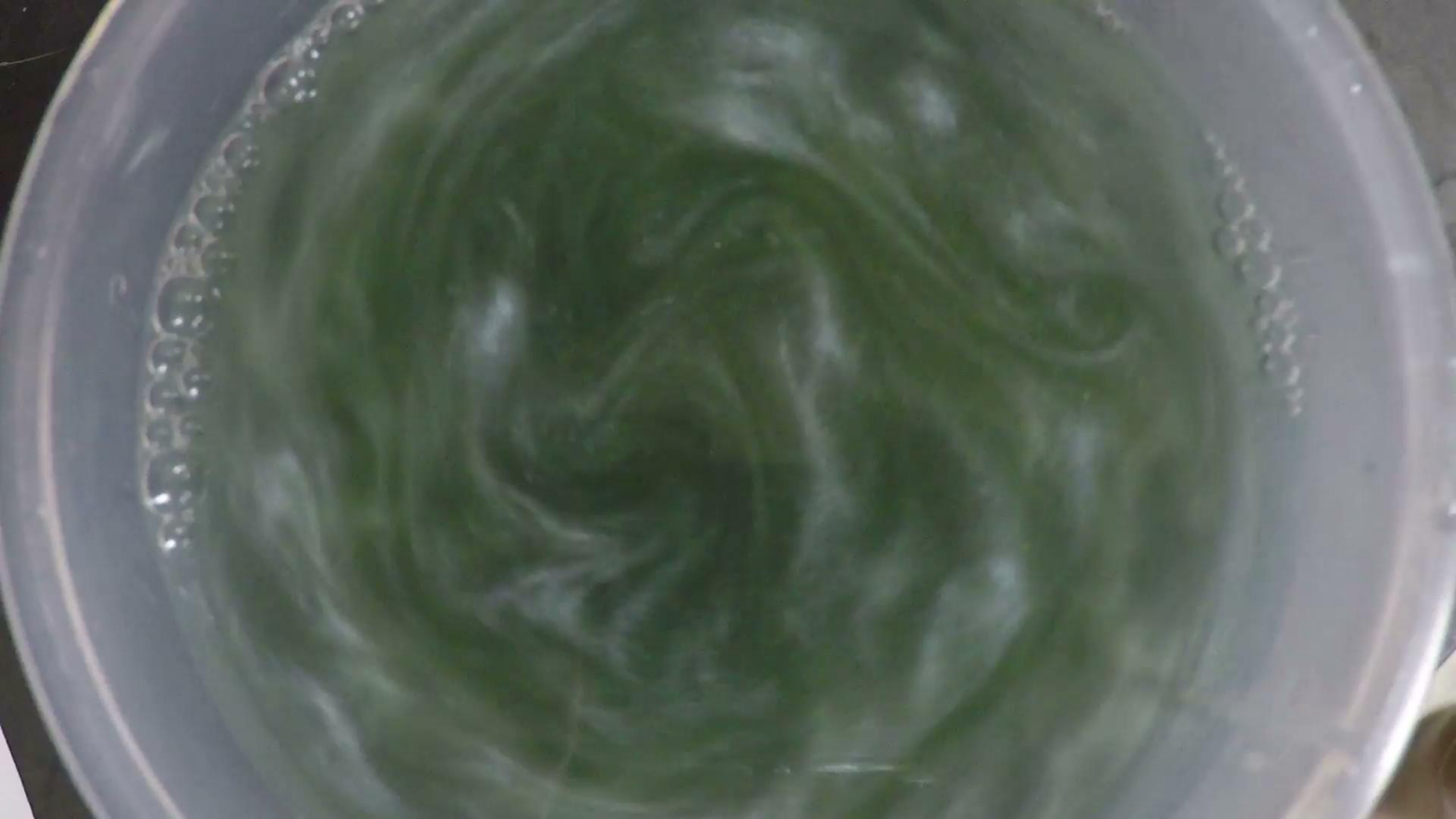
Troubles with measuring the mean flow

Measuring mean flow in a clear fluid can be a rather difficult task

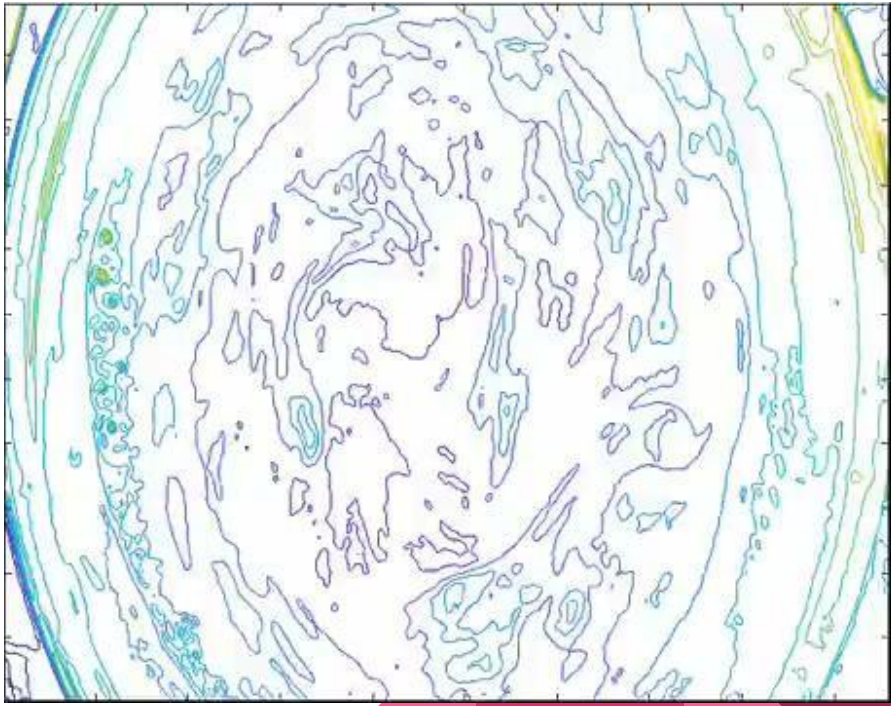
Using neutral buoyancy objects give us objects to track! . . . but we didn't find any

Dye grid would give us objects to track, and our filters could parse between vortex rings and dots, but it becomes very slow to record data

Rheoscopic fluid is a fluid used to visualize flows, however, our fluid presents itself with an interesting problem . . .



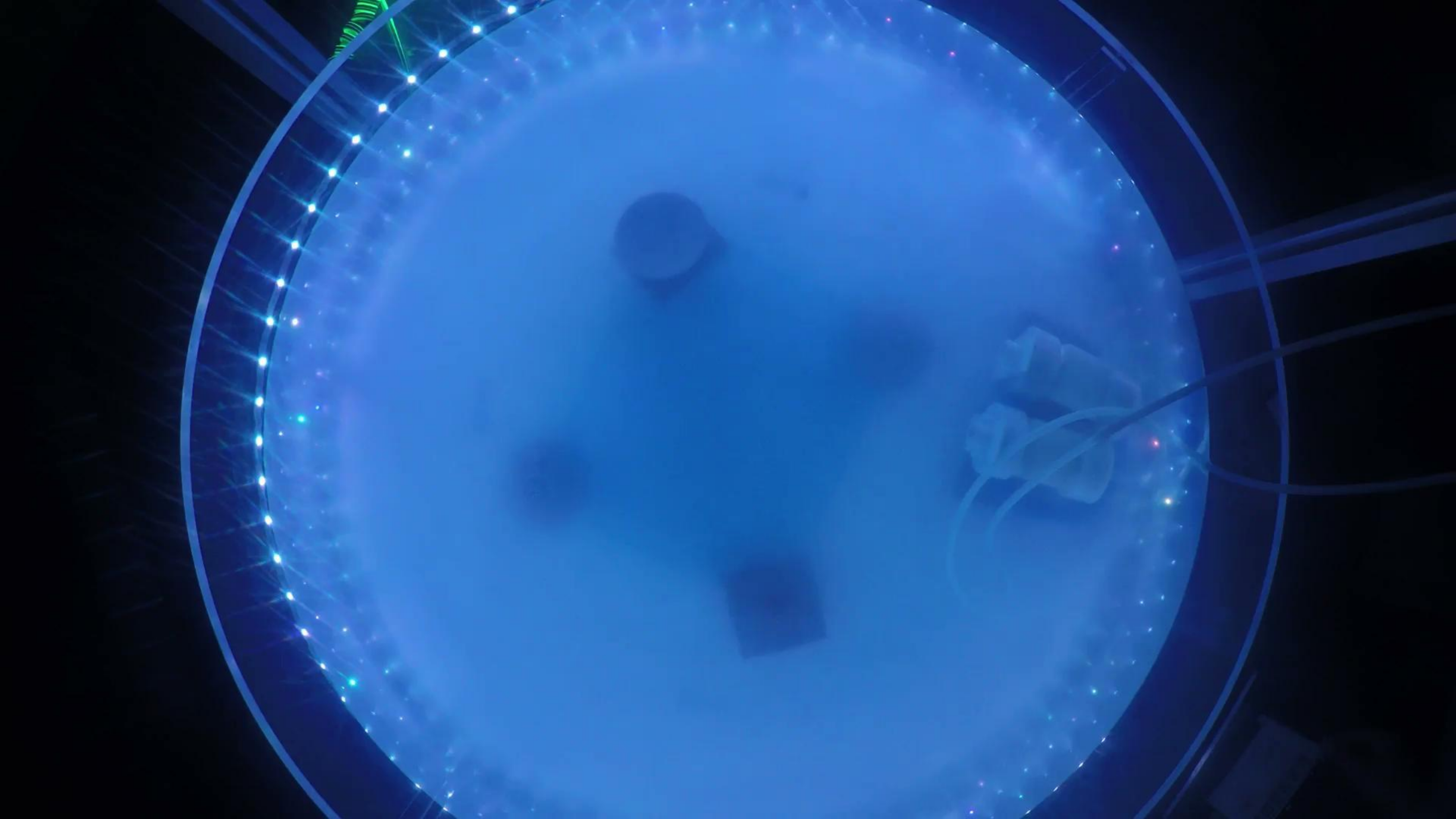
Attempt at Measuring the Mean Flow



Rheoscopic fluid and LEDs

In an attempt to enhance the rheoscopic fluid, LED strips were added to the tank to better illuminate the particles

This method approaches another method of understanding the fluid flow, which is known as Particle-Image-Velocimetry



Moving Forward

1) Tweaking code to run on all videos, and provide data
2) Teaching the tracker to better ignore noise, and capture more of the Vortex Rings
3) Continue exploration of methods of measuring the mean flow

Special Thanks

The NSF for making this REU possible

Joseph Biello for being a fantastic mentor, and dedicating countless hours to helping and teaching us

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