Tracking Walking Droplets in a Video

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Introduction

What is a Walking Droplet?

Bouncing Droplets

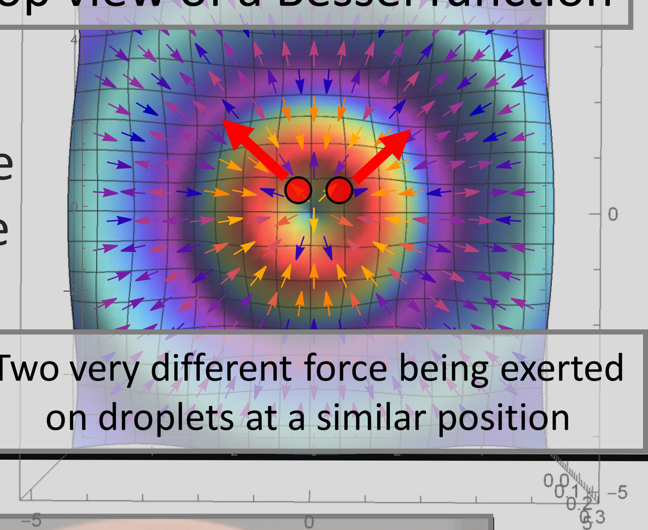
When a droplet is dropped into a liquid bath, the droplet can **bounce back up**. This is because a cushion of air separates the droplets from the surface. When the droplet bounce back up, it **perturbate the surface** of the bath with a Bessel function. This process can repeat but will often coalescence with the bath after some time. The lifetime of these droplets can be extended by using a liquid with an appropriate surface tension and the viscosity.

Walking Droplets

When the bath is vibrated vertically in a specific frequency, the bouncing droplets move horizontally in a **chaotic** trajectory . These are called the walking droplets. These droplets show phenomena **analogous to the particles in a quantum system**. The walls of the bath acts as an infinite potential. The bath used here have a circular wall, therefore our droplets should move like a particle in an infinite spherical well. The force exerted on a droplet by the surface is given by $-A\nabla h(\vec{r}, t)$. This cause the trajectory to be chaotic because the slope of a Bessel function can change drastically with small displacement.

A walking droplet

Top view of a Bessel function

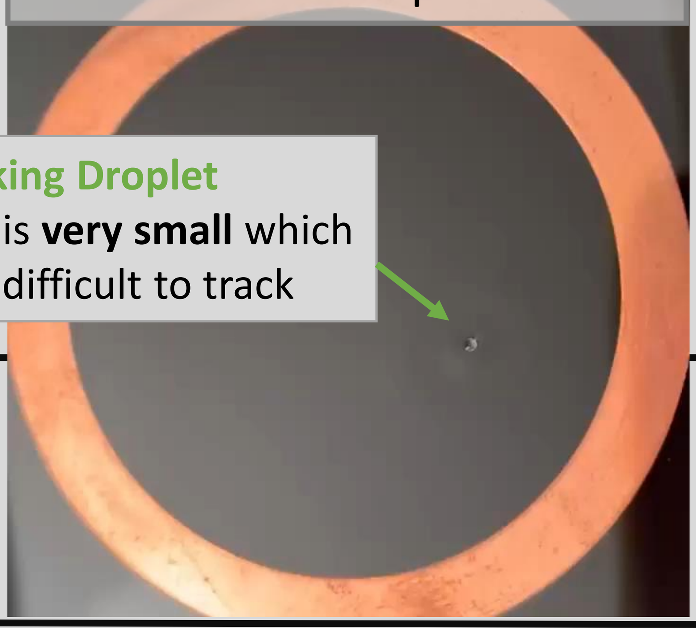


Two very different force being exerted on droplets at a similar position

AIM

- The walking droplets in a **hydrodynamic quantum experiment was filmed** using a camera
- The aim of the project was to write a software that could take the **video as an input**, then **output the trajectories of the walking droplets**

Video of the experiment



Walking Droplet

The droplet is **very small** which makes it difficult to track

Method

Multiple Object Tracking Problem

- Our method is strongly based on a MOT technique called the **Simple and Online Realtime Tracking** (SORT)
- **For each frame** in a video, MOT undergoes **4 stages** to track the objects

MOT Stages

SORT Methods

Our Methods

Detection Stage

Detects position of the objects in a frame

Faster Region CNN — Replaced by → **Circle Hough Transform**

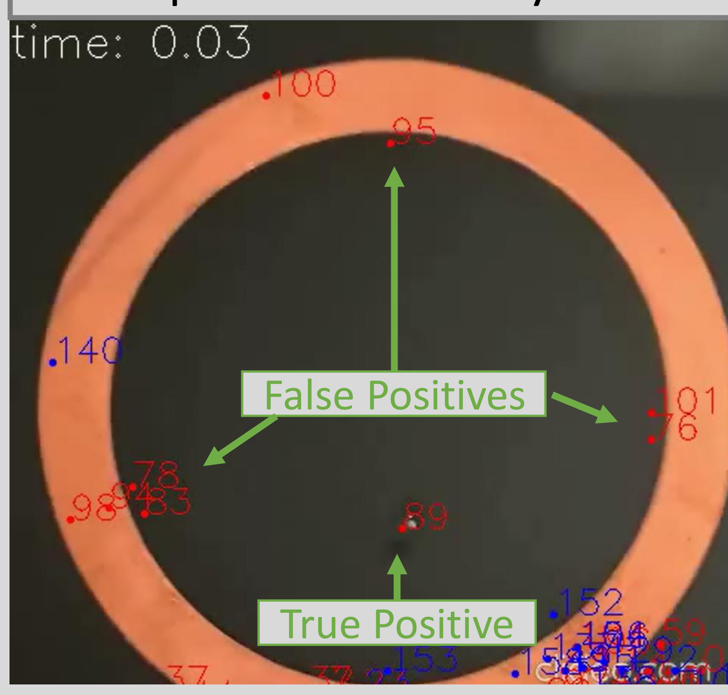
Faster Region CNN:

- A **neural method** for detecting objects in an image
- Requires labelled **training data**
  - Time consuming
- Not good at detecting small objects

Circle Hough Transform:

- A **non-neural method** for detecting circles
- No training data is required
- Produces **many false positives**
  - This problem is addressed in affinity stage

Droplets detected by CHT

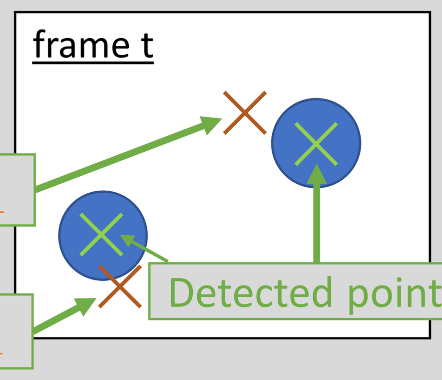


Feature Extraction Stage

Extracts features to be used in affinity stage for computing the cost matrix

Kalman Filter — Identical — **Kalman Filter**

- **Predicts** the position of the **tracklets in current frame**, using previous measurements. $\hat{x}_{t|t-1}$
- It is an autoregressive method



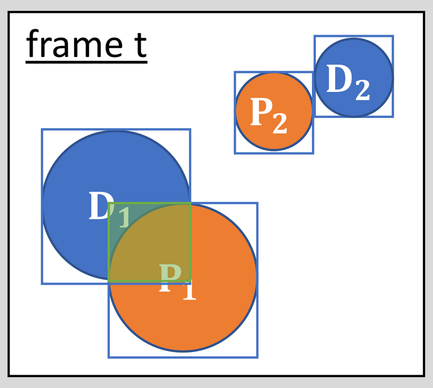
Affinity Stage

The **fitness** for every combinations of tracklets and detected droplet pair are calculated to construct a **cost matrix**

Intersection Over Union — Replaced by → **Euclidian Distance**, **Tracklet Age**, **CNN**

Intersection Over Union:

- IoU measures overlap between predicted and detected bounding boxes
- IoU = area of overlap / area of union
- Problem
  - Bounding boxes of **small objects don't overlap**
  - Then the cost matrix becomes a zero matrix



Predicted by Kalman Filter

Cost Matrix	Predicted 1	Predicted 2
Detected 1	$-\text{IoU}(P_1, D_1)$	$-\text{IoU}(P_2, D_1)$
Detected 2	$-\text{IoU}(P_1, D_2)$	$-\text{IoU}(P_2, D_2)$

Euclidian Distance, Tracklet Age, CNN:

- 3 terms are used to compute fitness for a pair of tracklet and a detected droplet

1. **Distance** between predicted tracklets and the detected position
2. **Tracklet age**: older tracklets gets prioritized
   This term reduces identity-switch of droplets and false psitives
3. **CNN prediction**: detected positions that look like droplets gets prioritized
   Training data was collected by running the program without this term
   Also reduces the identity-switch.

The three terms are added to compute the cost matrix

Association Stage

The detected droplets are mapped to a tracklet of the same identity to track the object across time

Hungarian Algorithm — Identical — **Hungarian Algorithm**

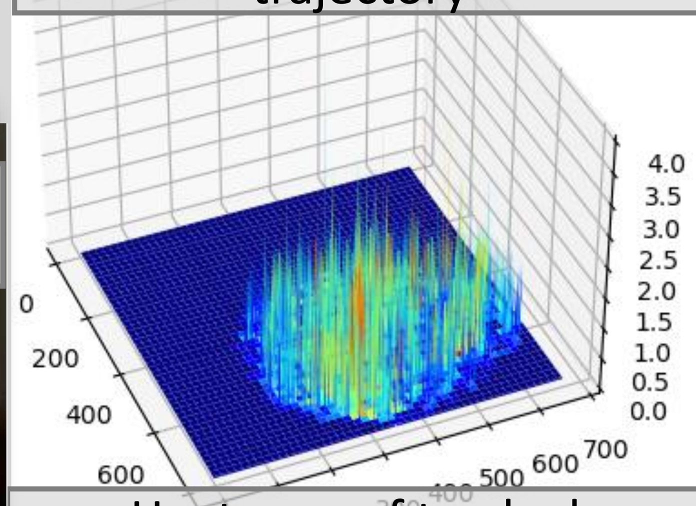
- Finds the **optimal combination of predicted and detected pair** that minimise the summed cost

Result

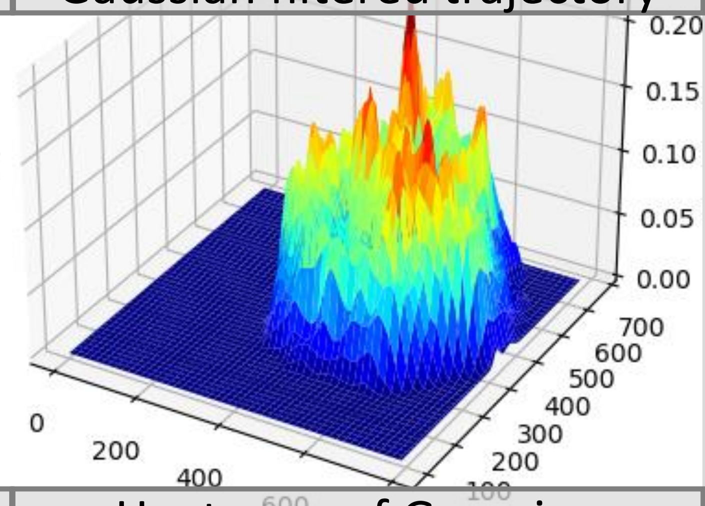
- The software could **successfully track a single droplet** in a 9 minutes video
- The trajectory was then used to plot the **probability density** and a **heat map** of the droplet
- **Gaussian filter** was applied to the trajectory to emulate a pattern that would have emerged in a longer video
- A **circular probability distribution** emerged, analogous to a particle in an infinite spherical well in quantum mechanics

Tracked trajectory of a droplet in a video

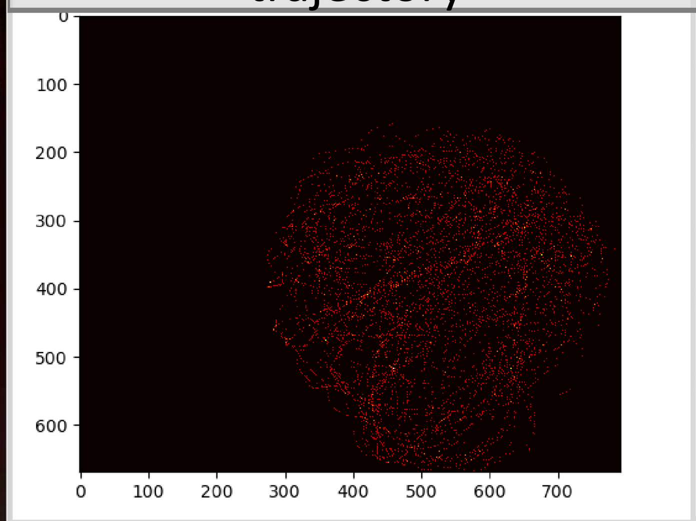
Probability density of tracked trajectory



Probability density of Gaussian filtered trajectory



Heat map of tracked trajectory



Heat map of Gaussian filtered trajectory