DETERMINING FLUID VISCOSITY USING COMPUTER VISION

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PROBLEM STATEMENT

The project aims to employ **computer vision** methodologies to determine the viscosity of a fluid by analyzing the motion of a ball falling through the fluid. By utilizing **Stokes' Law**, which correlates the drag force acting upon the ball traversing through a viscous fluid with its velocity, the objective is to derive the viscosity of that fluid.

IMPORTANCE

- Fluid viscosity measurement is crucial across industries like manufacturing, pharmaceuticals, and food processing.
- Accurate viscosity ensures product quality and process efficiency.
- Traditional methods like viscometer, rheometer are often time-consuming and invasive.
- Exploration of non-invasive alternatives, like computer vision, is necessary.


FER IN LAMINAR FLOW

ALGORITHMS USED

- **GMM Background Subtraction:** This algorithms takes the array of images and separates our objects or region of interests by using background model created during its run.

- **Canny edge detection algorithm:** It first classifies the edges as high or weak based on certain threshold. Pixels with values higher than edge threshold are marked white and rest as black.

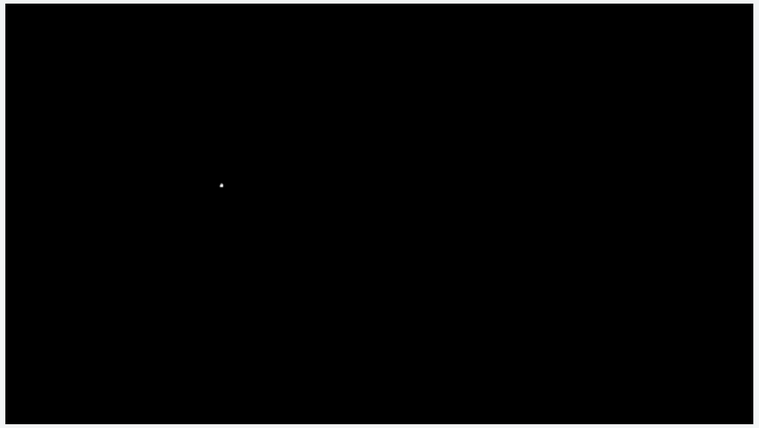
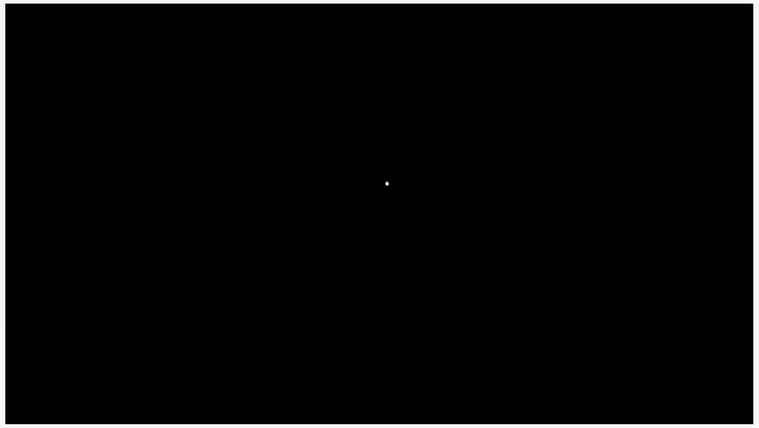
- **Curve Fitting:** Used to find the best-fitting curve or function that describes the data point.

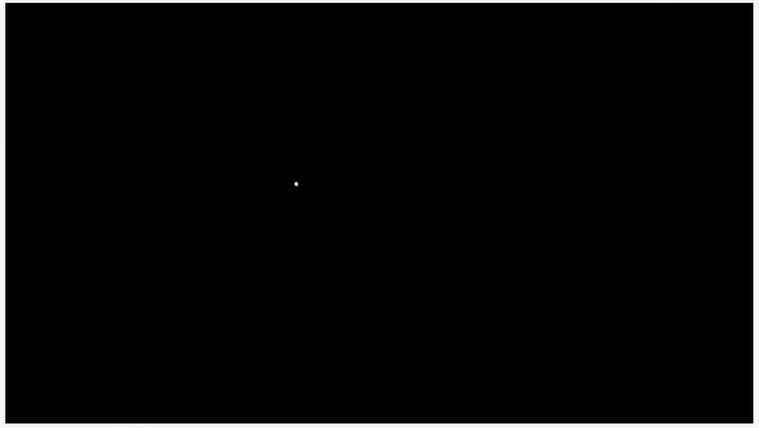
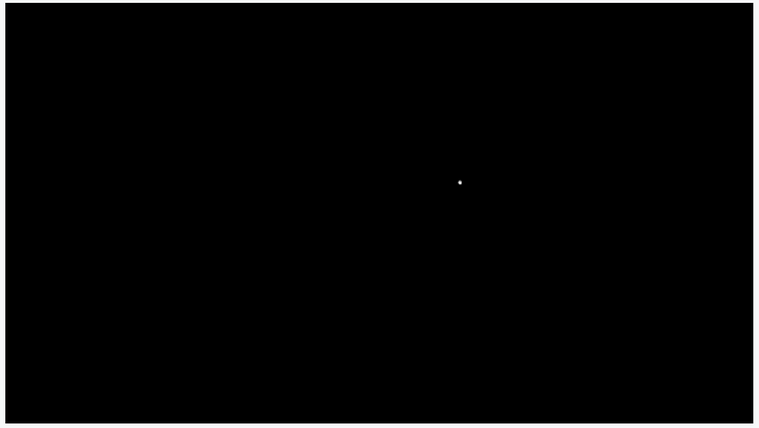
CODE SNIPPETS

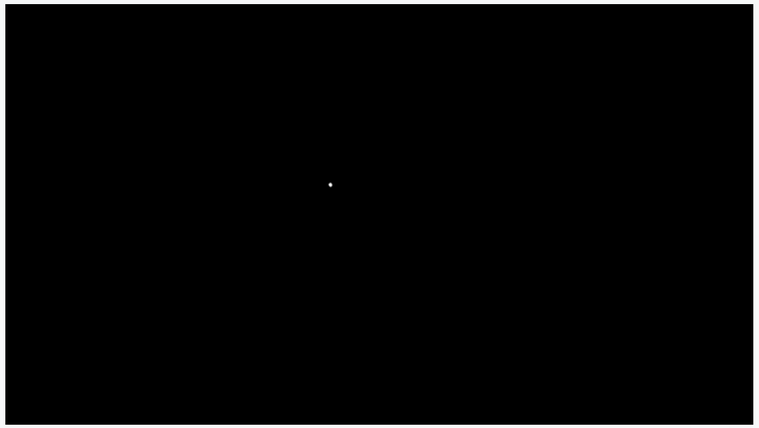
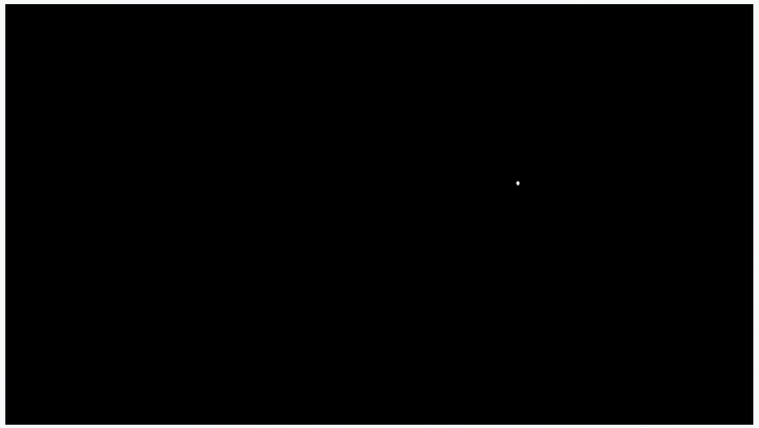
```
print("FPS:", fps)
fgbg = cv2.createBackgroundSubtractorMOG2(history=500,
    varThreshold=50, detectShadows=False)
crop_size = 200
edge_removal_threshold = 200
```

```
def remove_edges(image, edge_threshold):
    edges = cv2.Canny(image, 50, 200)
    edges = cv2.threshold(edges, edge_threshold, 255, cv2.THRESH_BINARY)[1]
    result = cv2.bitwise_and(image, cv2.bitwise_not(edges))
    return result
```

```
_, binary_mask = cv2.threshold(fgmask_no_edges, 50, 255, cv2.THRESH_BINARY)

contours, _ = cv2.findContours(binary_mask, cv2.RETR_EXTERNAL, cv2.CHAIN_APPROX_SIMPLE)

largest_contour = max(contours, key=cv2.contourArea, default=None)


if largest_contour is not None:
    M = cv2.moments(largest_contour)
    if M["m00"] != 0:
        cx = int(M["m10"] / M["m00"])
        cy = int(M["m01"] / M["m00"])

        cv2.circle(frame, (cx, cy), 5, (255, 255, 255), -1)
```

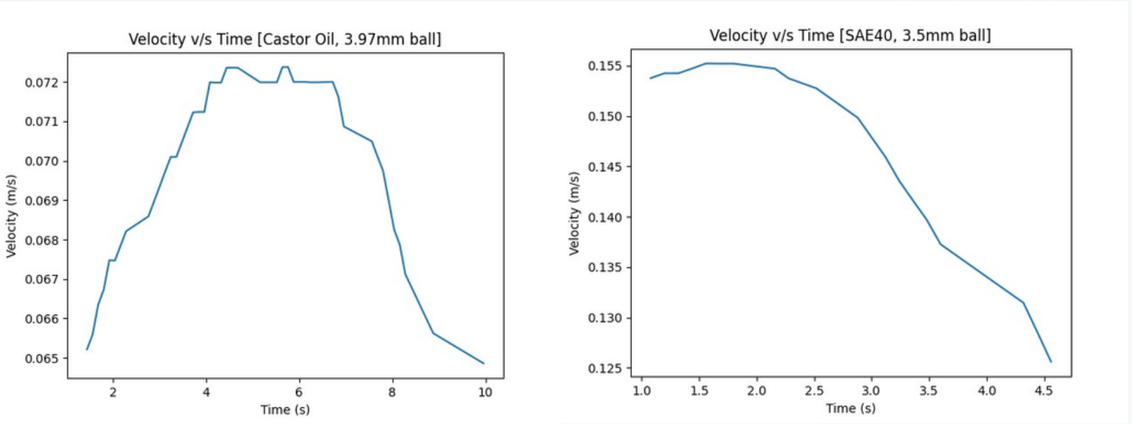




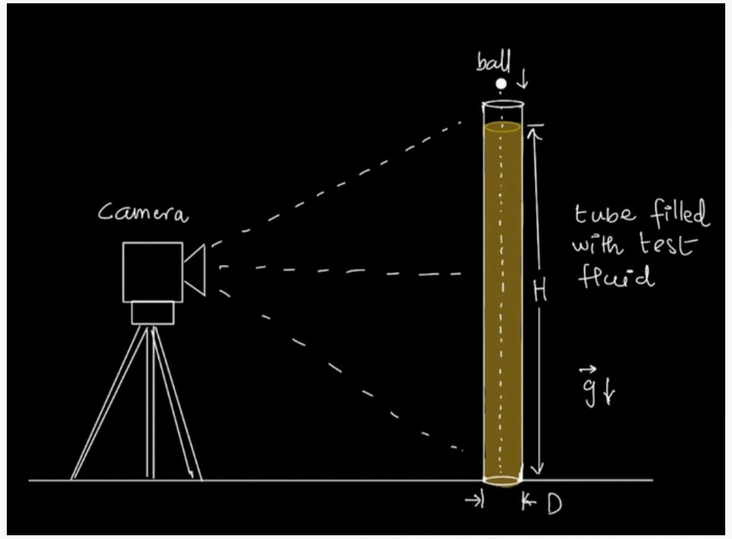



CHALLENGES

- Single-camera capture led to motion distortion due to the Doppler effect.
- Refined approach involved capturing separate video segments to minimize distortion and enhance accuracy.



- Ensuring the ball's proper release just inside the surface of the fluid is necessary to obtain an increasing velocity-time curve.
- Dropping the ball from a certain height or even partially immersed, led to a decreasing curve, which might be due to the impact force or surface tension on the surface of the liquid..



01

EXPERIMENTAL SETUP

- Transparent container filled with fluid.
- High-quality camera positioned for motion capture.
- Adjusted camera frame rate for detailed motion capture.

02

VIDEO CAPTURE

- Recorded falling ball using high-speed camera.
- Recorded separate video segments for each fluid pipe fraction to mitigate Doppler effect inaccuracies.

03

IMAGE PROCESSING

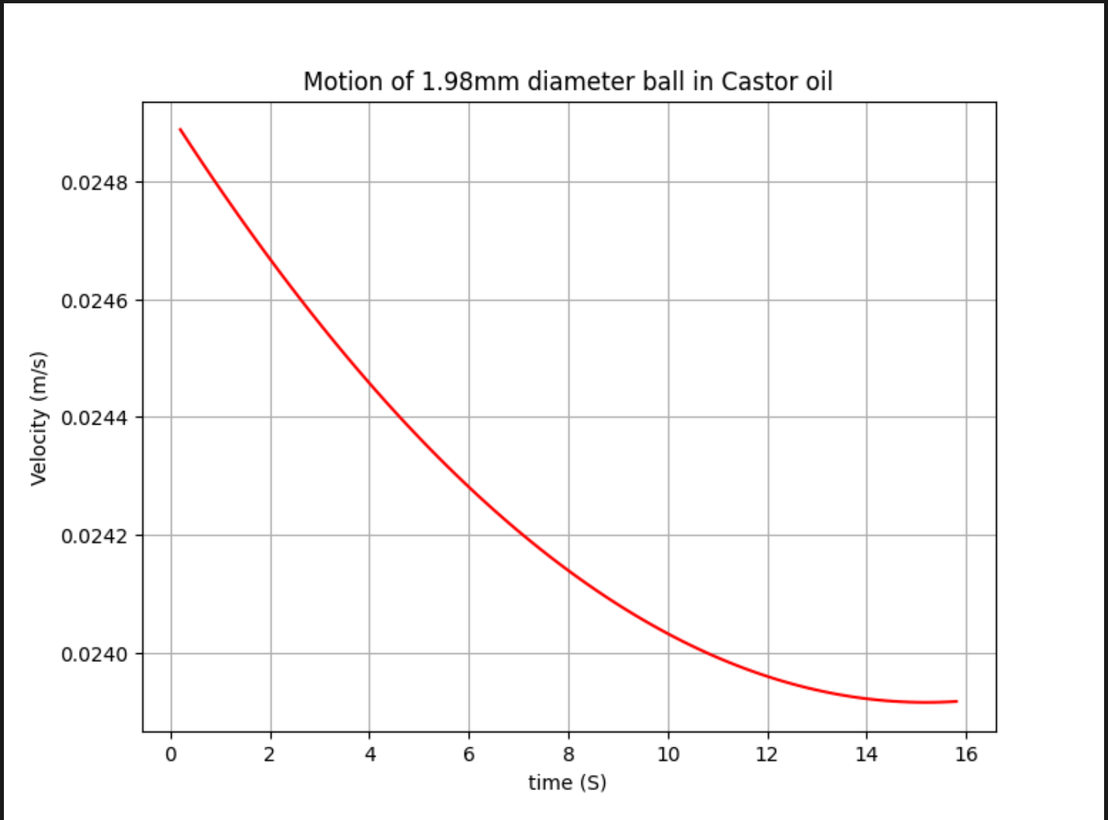
- Applied background subtraction algorithms to isolate moving ball.
- Utilized edge detection methods to identify ball's outline within frames.

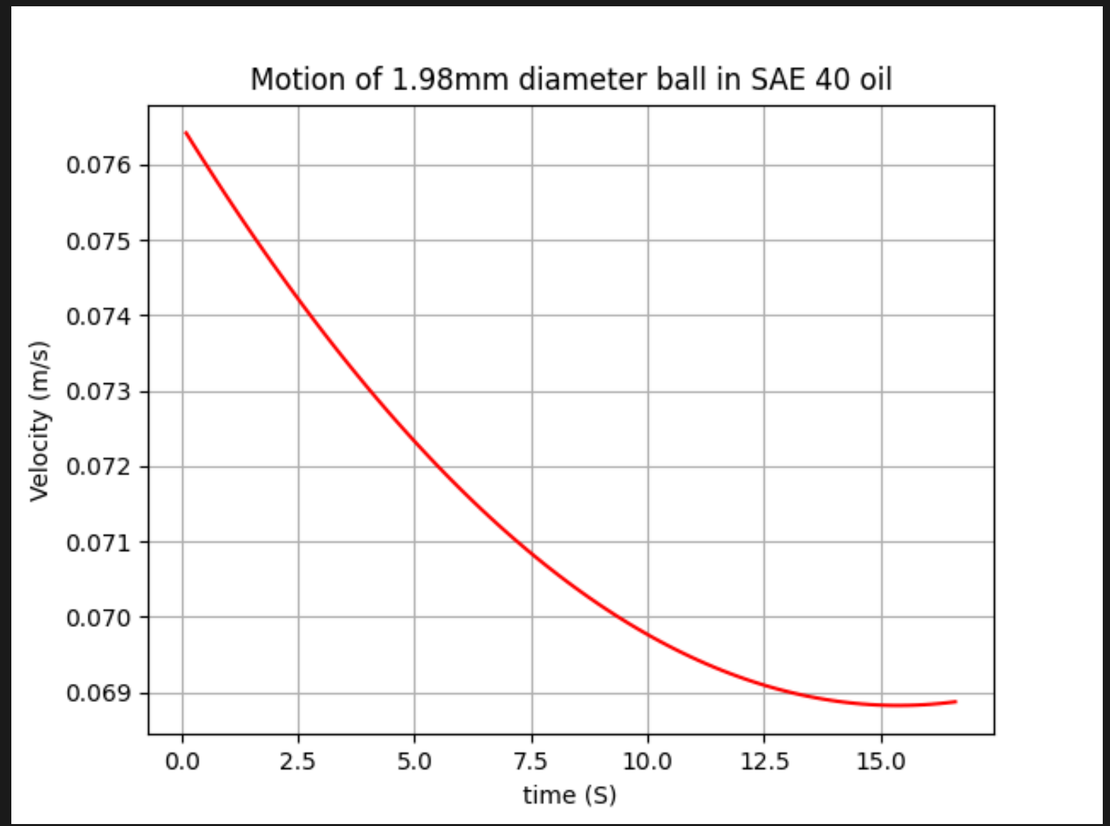
04

MOTION ANALYSIS

- Employed centroid tracking to monitor ball's position over time.
- Calculated ball displacement and time difference for velocity determination.

RESULTS


Motion of 1.98mm diameter ball in Castor oil
Velocity (m/s)
0.0248
0.0246
0.0244
0.0242
0.0240
0
2
4
6
8
10
12
14
16
time (S)


Motion of 1.98mm diameter ball in SAE 40 oil
Velocity (m/s)
0.076
0.075
0.074
0.073
0.072
0.071
0.070
0.069
0.0
2.5
5.0
7.5
10.0
12.5
15.0
time (S)

According to Stoke's law, viscous force acting on a spherical body falling through a viscous liquid is given by:

$$F_d = 6\pi\eta r v$$

$\eta \equiv$ coefficient of viscosity of fluid.

$r \equiv$ radius of the body.

$v \equiv$ terminal velocity.

F_d acts against the motion of the body.

The ball is also acted upon buoyant force (F_B) against its motion.

Both these forces together oppose the gravitational force (F_g), which acts downwards or along the motion.

The body attains terminal velocity because the forces get balanced at some point in time; i.e. the $(F_d + F_b)$ increases or decreases and matches the value of F_g.

i.e. $$F_g = F_d + F_b$$

$$\therefore F_d = F_g - F_b \quad \text{——— (1)}$$

$$F_g = mg = \rho V g$$

$$F_g = \rho \times \frac{4}{3}\pi r^3 \times g$$

and, $$F_b = \sigma V g = \frac{4}{3}\pi r^3 \cdot \sigma \cdot g$$

where, $\rho \equiv$ density of the material of the ball.

$\sigma \equiv$ density of the fluid through which it is falling.

$\therefore$ (1) $\Rightarrow 6\pi\eta r v = \frac{4}{3}\pi r^3 (\rho - \sigma) g$

$$\therefore \quad \boxed{\eta = \frac{2}{9}\frac{(\rho-\sigma) g r^2}{v}}$$

unit of $\eta = N\cdot s/m^2$ or poiseuille (PI)

Ladenberg corrections

↳ Introduced due to the finite width and depth of the tube through which the ball is falling.

$$\boxed{v = v'\left(1 + \frac{2.4r}{R}\right)\left(1 + 3.3\frac{r}{H}\right)}$$

$v' \equiv$ observed terminal velocity.

$R \equiv$ internal radius of the tube

$H \equiv$ depth of the fluid contained in the cylinder.

density of the ball, $\rho = 7800\ kg/m^3$

diameter of ball $= 1.98 \times 10^{-3} m$

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Castor oil

$\sigma = 959\ kg/m^3$ $\qquad \boxed{\eta = 0.58\ Ns/m^2}$ ↳ Actual η

$$\eta = \frac{2}{9}\frac{(\rho-\sigma) g r^2}{v}$$

4/7

$$\eta = \frac{2}{9}\cdot\frac{(7800-959)\times 9.81\times (0.99\times 10^{-3})^2}{v}$$

$$\eta = \frac{2}{9}\cdot\frac{(7800-959)\times 9.81\times 0.00099^2}{0.0239}$$

$$\boxed{\eta = 0.612\ Ns/m^2 = 612\ cP}$$

$$\boxed{\%\ error = \frac{612-580}{580}\times 100 = 5.52\%}$$

↳ can be possibly rectified using the Ladenberg correction.

$$v = v'\left(1 + \frac{2.4r}{R}\right)\left(1 + 3.3\frac{r}{H}\right)$$

$$v = 0.0239\left(1 + \frac{2.4\times 0.00099}{29.725\times 10^{-3}}\right)\left(1 + \frac{3.3\times 0.00099}{2}\right)$$

$$v = \underline{0.0258\ m/s}$$

$$\therefore \quad \eta' = \frac{2}{9}\frac{(7800-959)\times 9.81\times 0.00099^2}{0.0258}$$

$$\eta' = 0.566 \text{ Ns/m}^2 = 566 \text{ cP}$$

$$\text{new \% error} = \frac{580 - 566}{580} \times 100 = 2.41\%$$

SAE 40

$\sigma = 880 \text{ kg/m}^3$

Actual η

$\eta = 209 \text{ cP}$

$$\eta = \frac{2}{9} \frac{(7800 - 880) \times 9.81 \times 0.00099^2}{0.069}$$

$$\eta = 0.214 \text{ Ns/m}^2 = 214 \text{ cP}$$

$$\% \text{ error} = \frac{214 - 209}{209} \times 100 = 2.3\%$$

$$v' = 0.069 \left(1 + \frac{2.4 \times 0.00099}{0.025}\right)\left(1 + \frac{3.3 \times 0.00099}{2}\right)$$

$$v' = 0.0691$$

$$\therefore \eta' = \frac{2}{9} \frac{(7800 - 880) \times 9.81 \times 0.00099^2}{0.0691}$$

$$\eta' = 0.213 \text{ Ns/m}^2 = 213 \text{ cP}$$

$$\therefore \text{new \% error} = \frac{213 - 209}{209} \times 100$$

$$\text{new \% error} = 1.91\%$$

FUTURE WORK

Objective

Develop/derive an **error correction factor** or equation that rectifies the challenge that arose due to the **Doppler effect.**

Objective

Investigate using **wiggle features** in the image processing algorithm to enhance the detection and tracking of small-scale fluid movements. Wiggle features can capture subtle changes in the fluid's motion, providing more detailed information about its velocity profile.

Objective

Explore using the **background-oriented Schlieren technique** to measure the velocity of the fluid as it flows through a transparent horizontal pipe. This technique can provide a visual representation of the fluid's density gradients, which can be used to infer its velocity.

REFERENCES

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THANK'S FOR WATCHING