Software Development for Material Characterization using High-Speed Image Analysis

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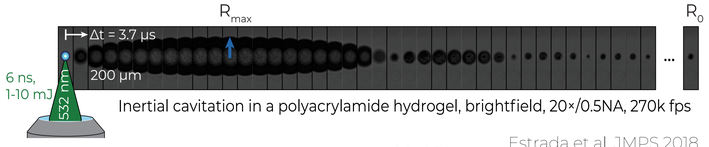
Introduction

Inertial cavitation generated by a single laser pulse can be used as a mechanical characterization technique



Inertial cavitation in a polyacrylamide hydrogel, brightfield, 20×/0.5NA, 270k fps

Estrada et al. JMPS 2018

Ultra-high-speed video is acquired (>2Mfps)

400x250 px
256 frames

Shimazdu HPV-X2
High-speed camera

TL

Imaging Objective 10×

Focusing Objective 10×

Existing need for bubble kinematics software

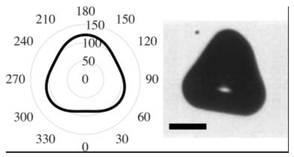
Single pulse is triggered

Pulsed Nd:YAG
1064 → 532nm
4ns single shots

Laser

beam expander

beam profiler



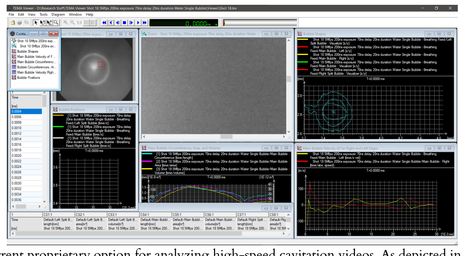
Non-spherical bubbles arise from instabilities during the deformation process

High velocity and low viscosity may produce e.g. Fourier order 3 oscillation

Murakami et al. Ultrason Sonochem 2020

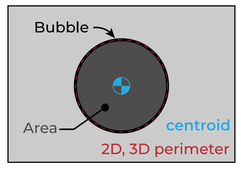
Objectives

Improve state-of-the-art software for bubble kinematics

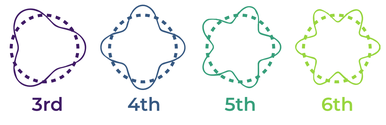


The current proprietary option for analyzing high-speed cavitation videos. As depicted in the diagram above, TEMA presents minimal data in an outdated interface with no option for bubble fitting.

Quantities of interest:

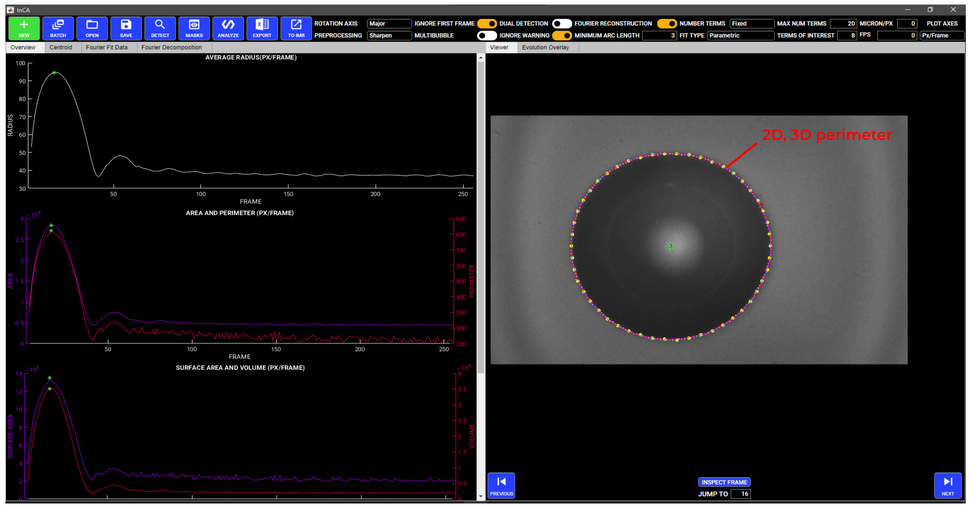


Fourier vibration mode
(alternately could be spherical harmonic)



A combination of 2D and 3D properties along with the Fourier vibration mode is sufficent data to use material fit software to develop a material characterization model for use in various fields.

InCA with Designed GUI



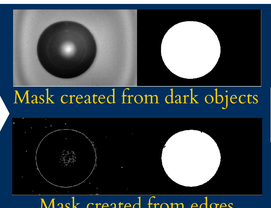
A screenshot of Inertial Cavitation Capture (InCA)

From data gathered by Shimadzy HPV-X2 High speed camera observing inertial cavitaion in a sample of uncured PDMS

Algorithm Flowchart

Phase I: Detection

Image preprocessing: User-defined sharpening or softening



Masks compared and combined

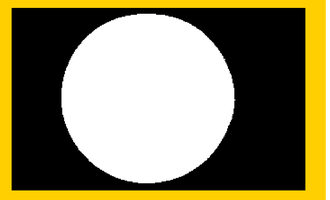
Phase II: 2D Analysis

Number of 'on' pixels corresponds to Area.

Number of 'on'pixels neighbored by 'off' pixels corresponds to Perimeter.

Centroid determined via center-of-mass formula

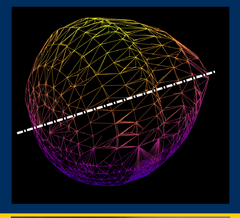
Average radius calculated by averaging distances from 50 periemter points to centroid



Phase III: 3D Analysis

Surface area caluclated by revolving perimeter points around major axis and summing the surface area of frustrums.

Volume caluclated by revolving perimeter points around major axis and summing the volume of frustrums.

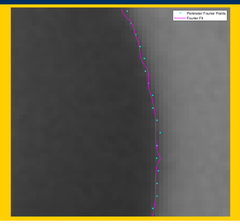


Phase IV: Fourier Fit

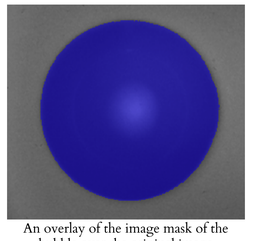
Points on the perimeter are chosen as inputs to the fit

A user-defined number of Fourier series components is declared as the fit function

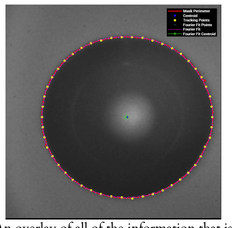
MATLAB fits the specified Fourier series function of user-defined order to the perimeter points



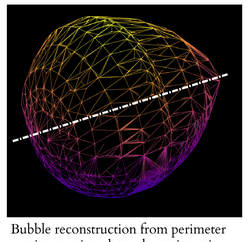
Example Results/Interpretation



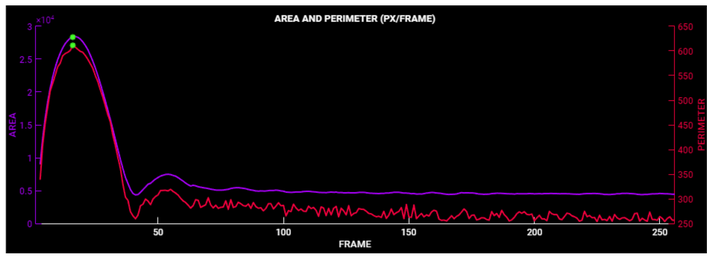
An overlay of the image mask of the bubble over the original image



An overlay of all of the information that is collected about the bubble from the mask

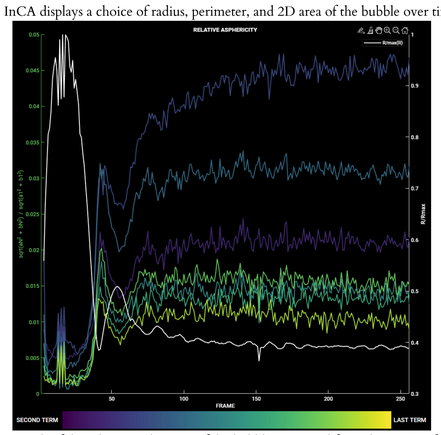


Bubble reconstruction from perimeter point rotation about the major axis



Bubble radii are extracted for material characterization

InCA displays a choice of radius, perimeter, and 2D area of the bubble over time.



A graph of the relative asphericity of the bubble generated from the Fourier fit of the bubble perimeter for each frame

Conclusions and Future Work

The algorithms and software interface developed successfully meet performance metrics. InCA is now capable of processing images for incorporation into material fit software.

Prior issues in the detection of bubbles were due to ghosting of past and future frames and overlapping bubbles.

Possible solutions to this include developing edge tracing algorithms to more precisely detect the edge of a bubble and differentiate it from an overlapping bubble.

Further investigations include bubble fitting using polar coordinates and spherical harmonics, and development of a multi-viewpoint platform and image processing scheme.

Acknowledgements

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