University of Stavanger

Novel optical method for reconstruction of axisymmetric capillary wave surface topography:
theory, simulation, and experimentation

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Outline

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- Background and motivation
- New optical method
- Numerical simulations
- Experimentation
- Results
- Conclusion

Background and Motivation

Liquid Properties

- Surface tension

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- Viscosity

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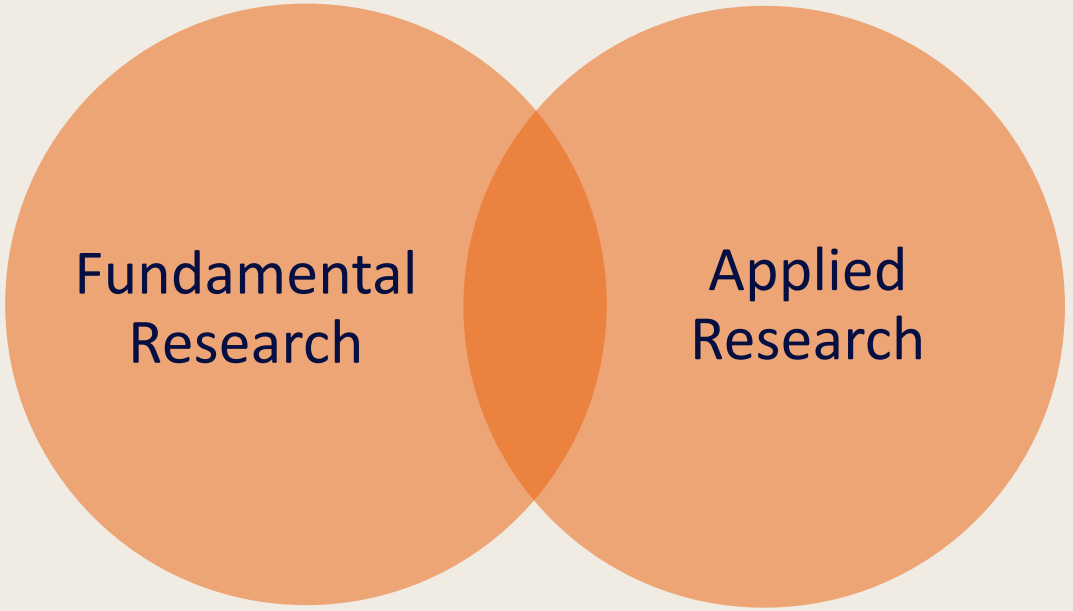
Project Goal

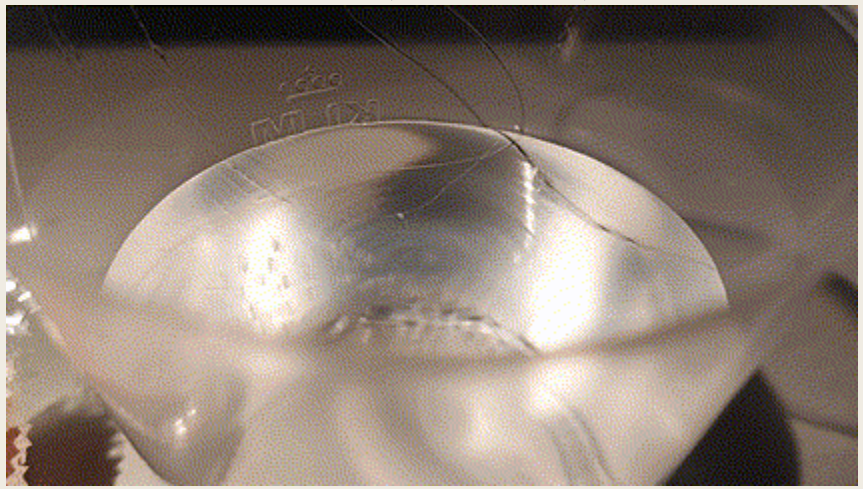
- Non-intrusive method for measurement of surface tension and viscosity
- Why?
  - Understanding interface behavior
  - Modeling and simulation for industrial applications
- Existing method/solutions
- Personal goals
  - Cheap, simple and mobile setup

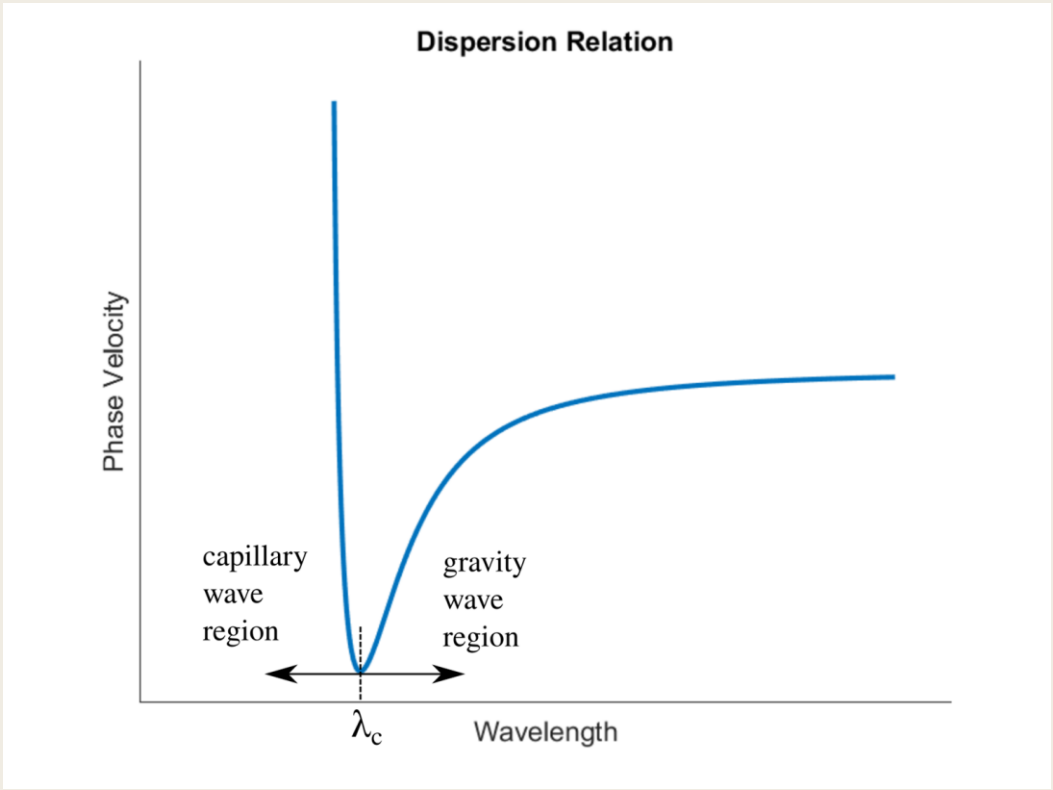


Capillary Waves

- Interfacial tension is dominant force
- Characterized by tiny amplitude and high frequency
- Linear wave theory (dispersion eq.)

$$\omega^2 = k\left(g + \frac{k^2\sigma}{\rho}\right)$$

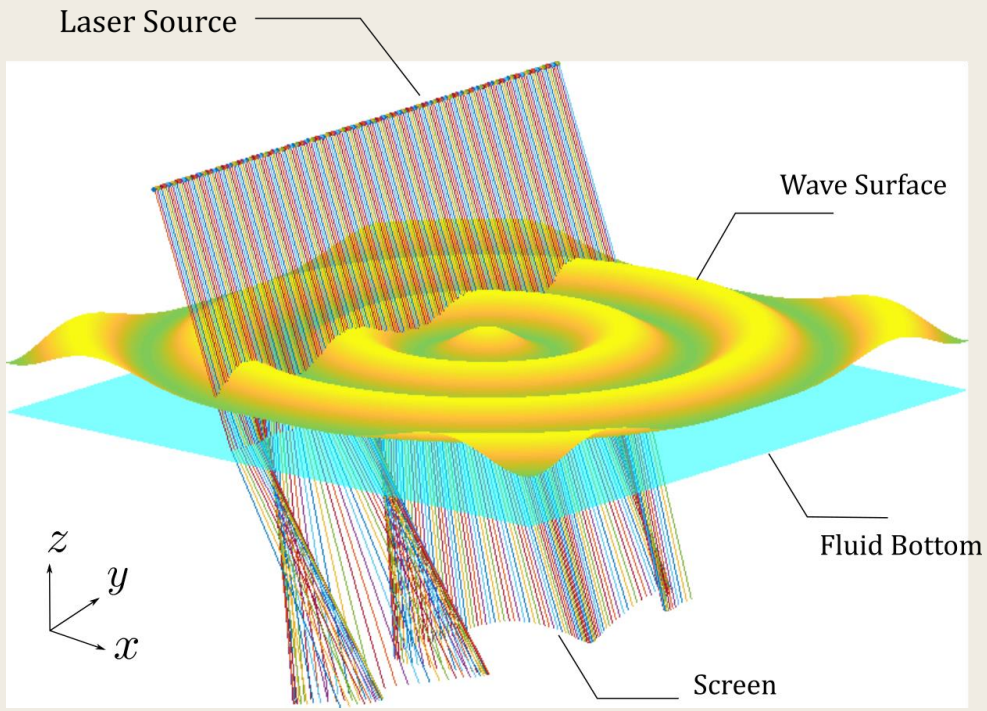




New Optical Method

Numerical Validation

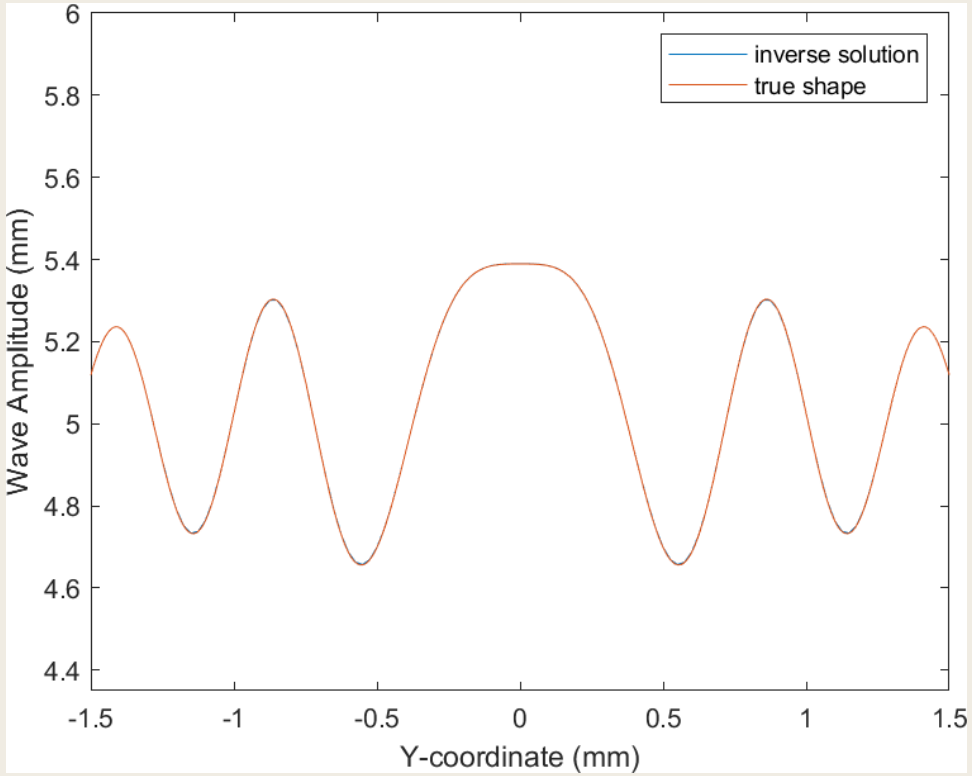
- Using refraction as magnifier
- Ray-tracing simulator
  - MATLAB
  - Constrained and unconstrained numerical optimization
- Geometric optics
  - Forward ray-tracing problem
  - Inverse ray-tracing problem

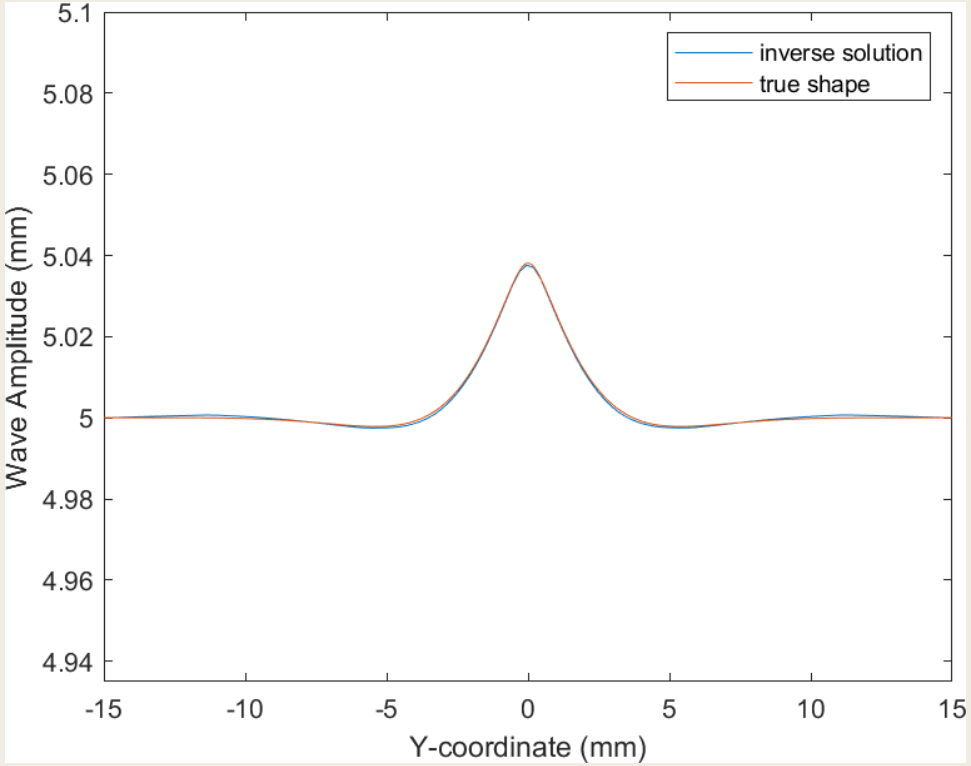


Mukim et al., AIP Advances, 2022

Numerical Validation

- Good accuracy for low and high curvature values

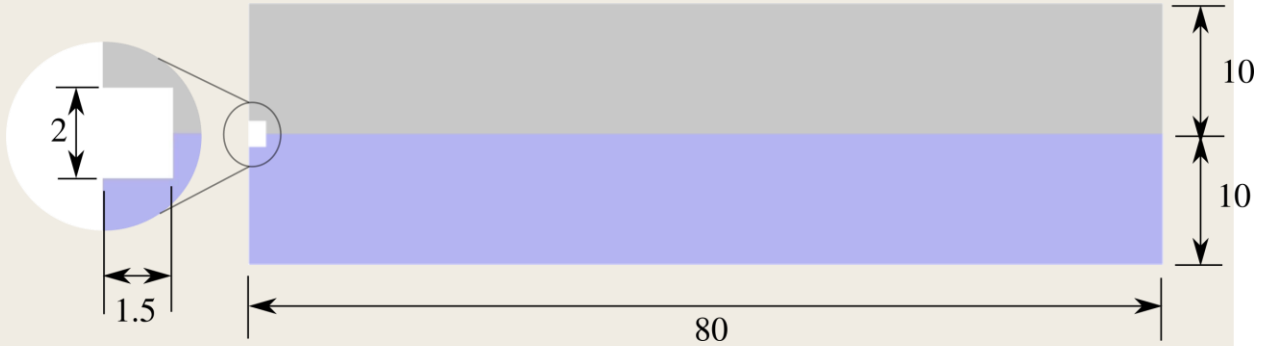


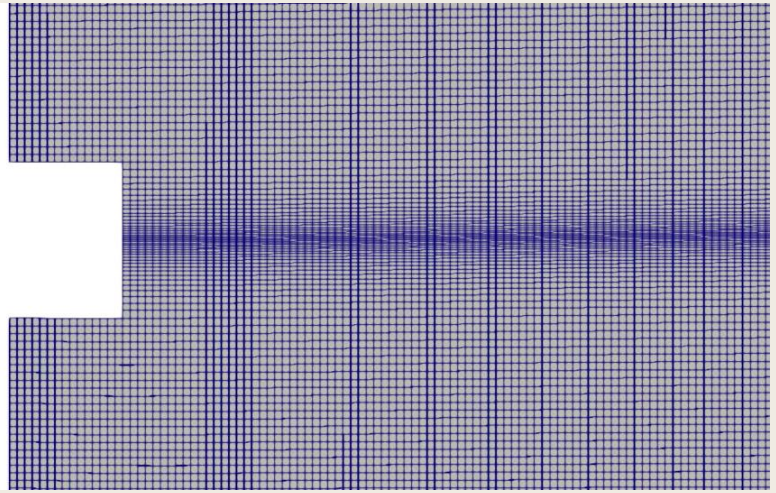


Numerical Simulations

Numerical Setup

- Objectives
  - Verify linear wave theory
  - Help in design of experiment
- Planar symmetric setup
- Numerical experiments
  - Frequency **20** & 40 Hz
  - Interfacial tension 20 & **70** mN/m
- Amplitude 0.2 mm
- Graded mesh and dynamic mesh motion

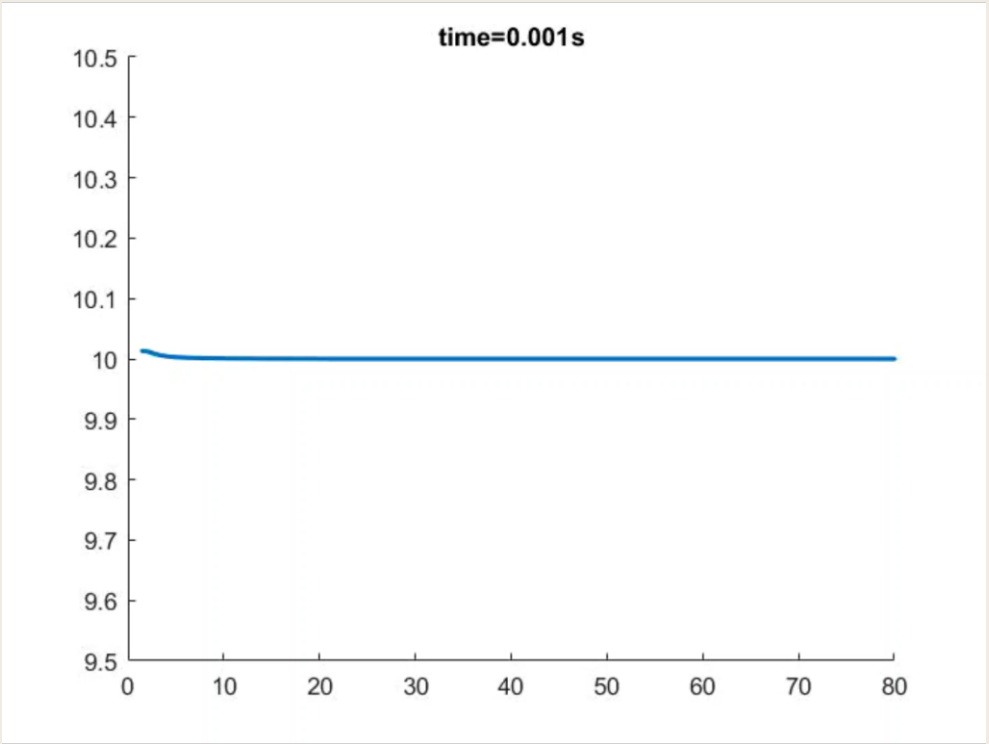




VoF Results

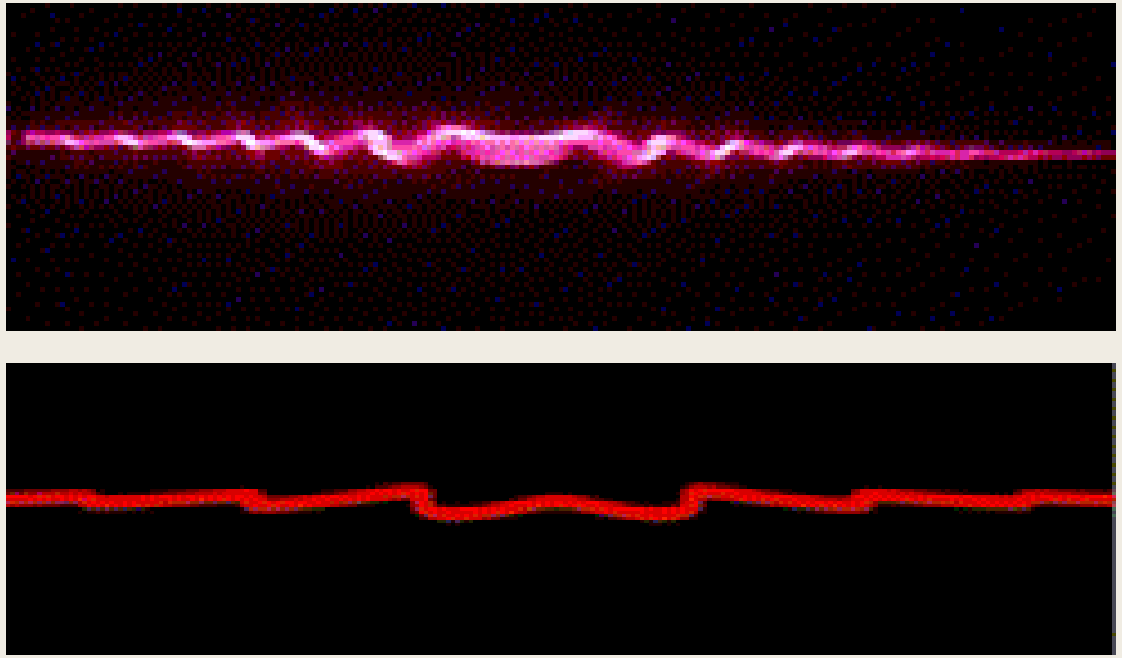
- Volume fraction

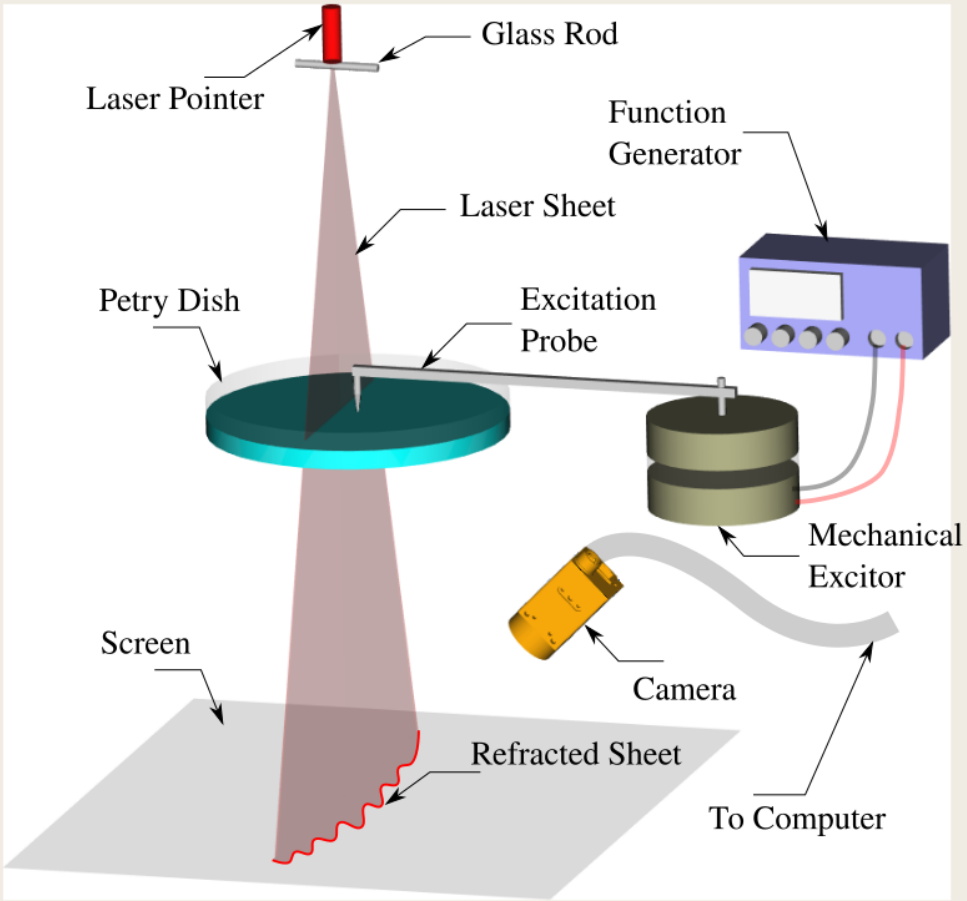
- Interface



Experimentation

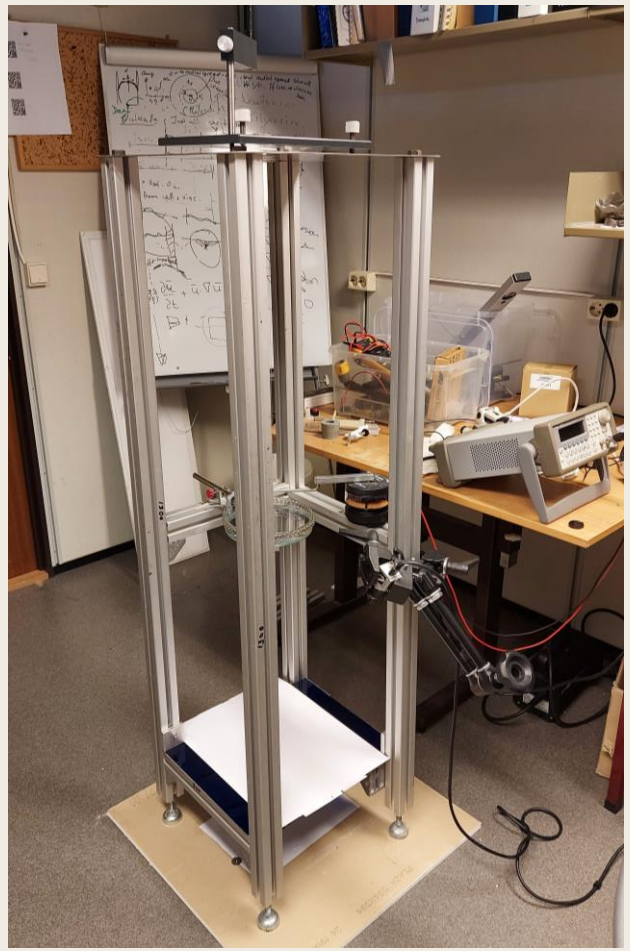
Proof of Concept





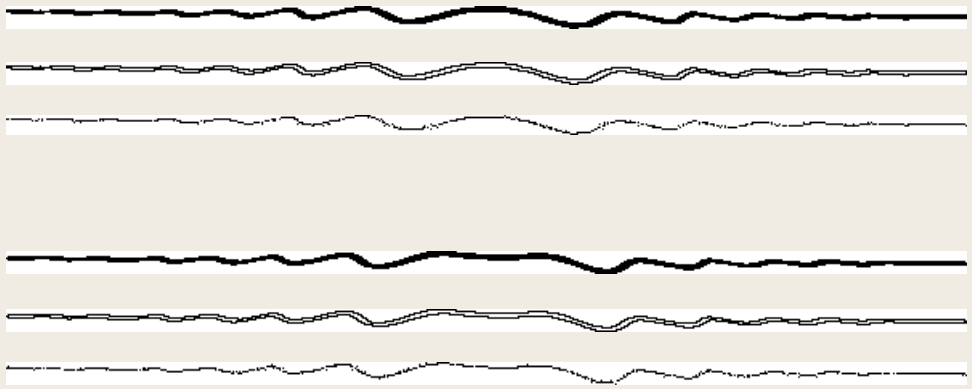
Setup

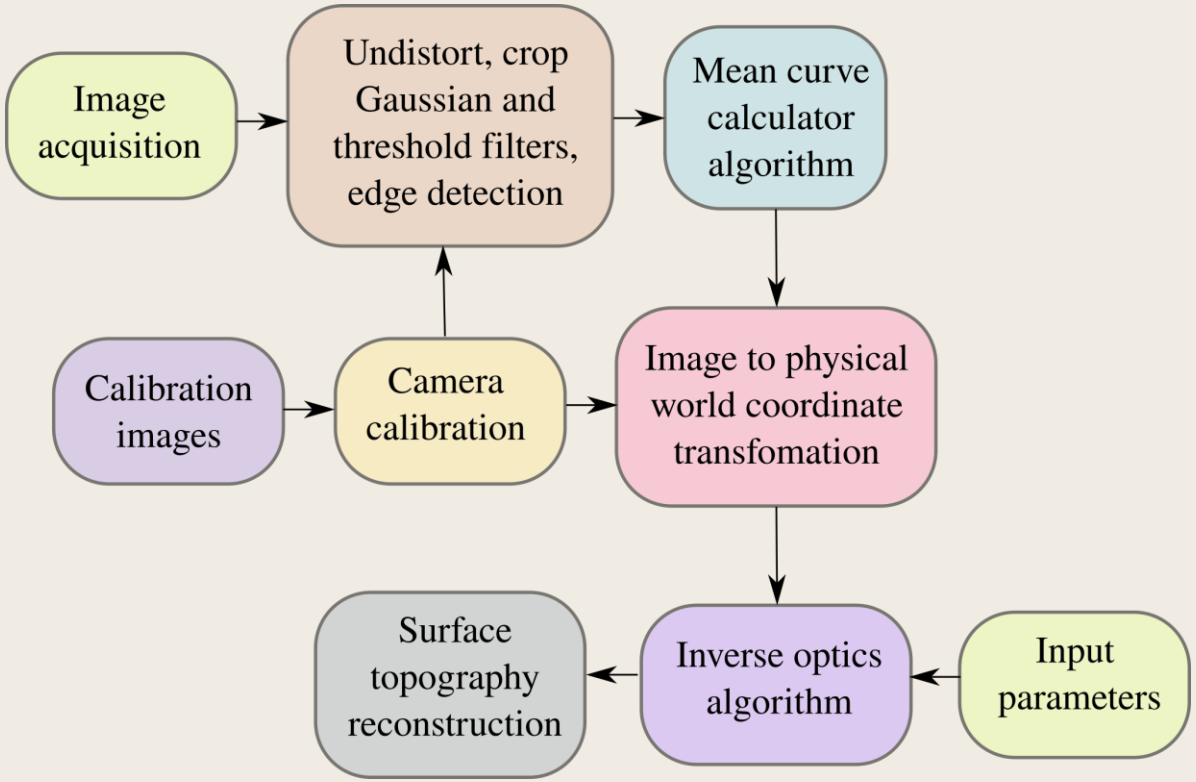
- Laser sheet
- Mechanical excitor for wave generation
- Signal generator to drive the mechanical excitor at given frequency and amplitude
- High speed camera for image capturing
  - Smart phone camera can be used
- Tweaks in code for experimentation
  - Point laser source instead of line source
  - Glass Petry dish



Post-processing

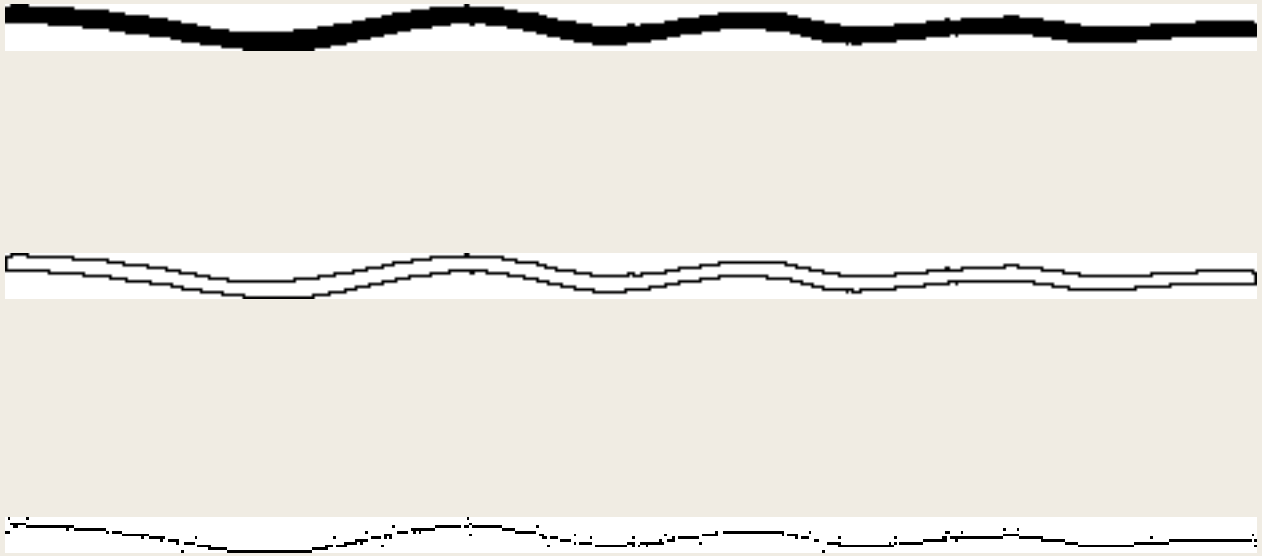
- Mean Curve Calculation



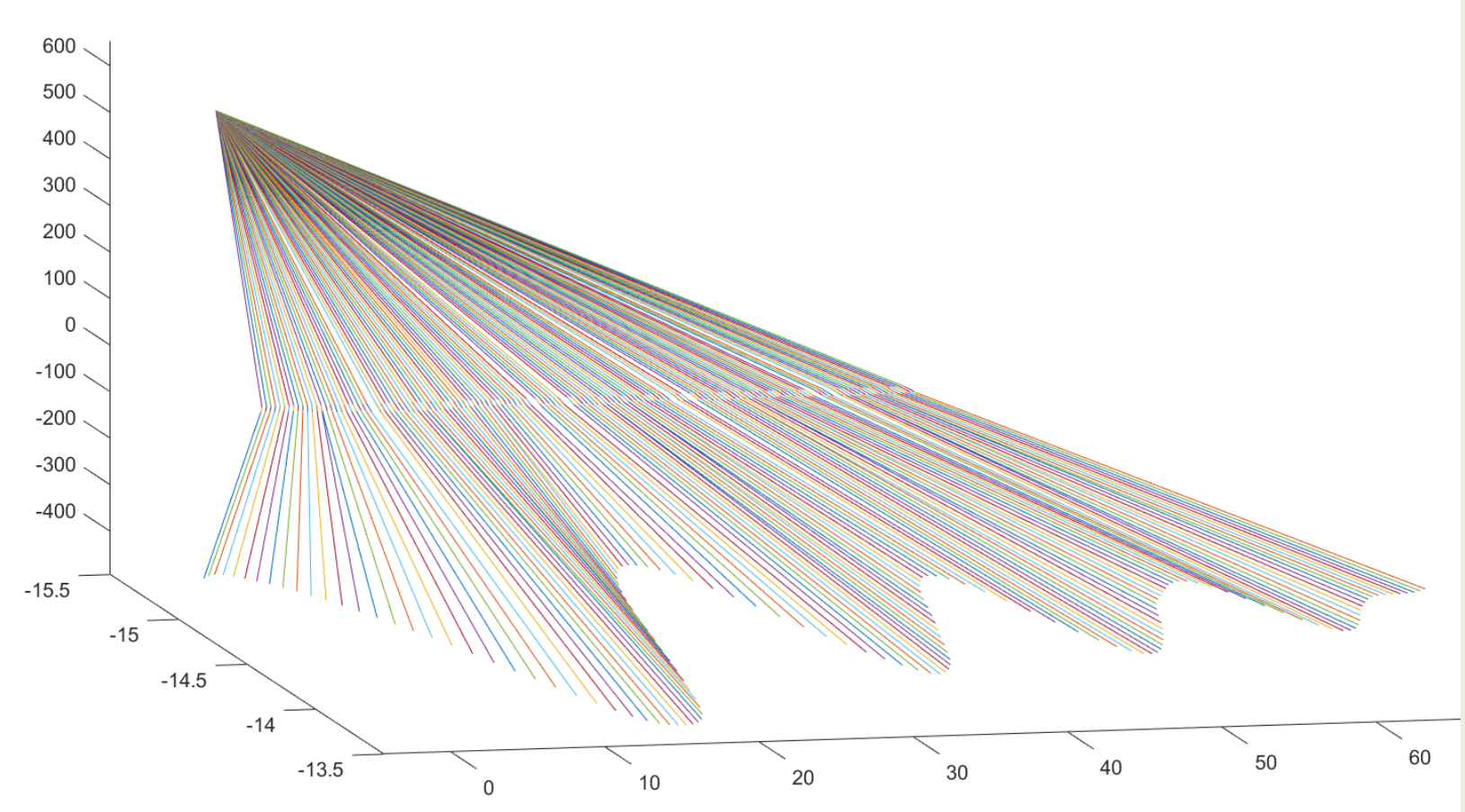


Results

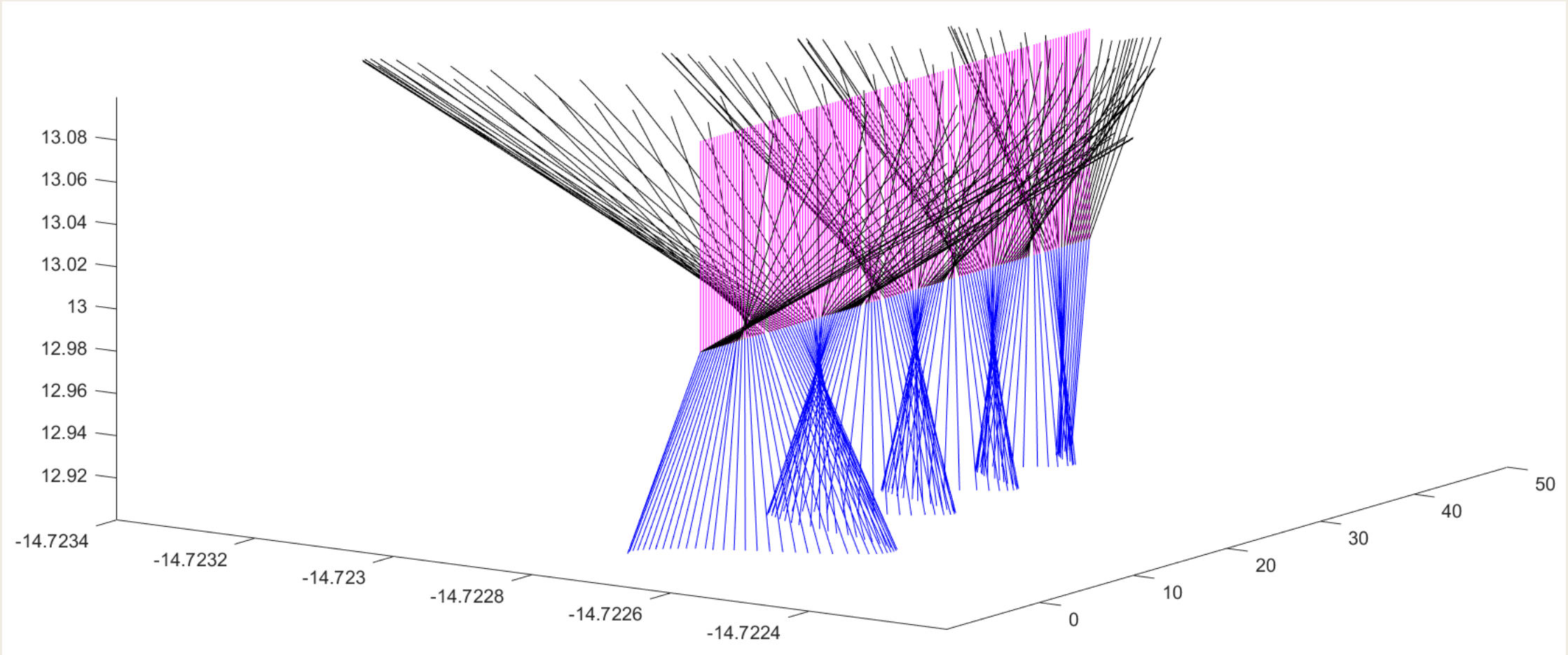
Image Processing



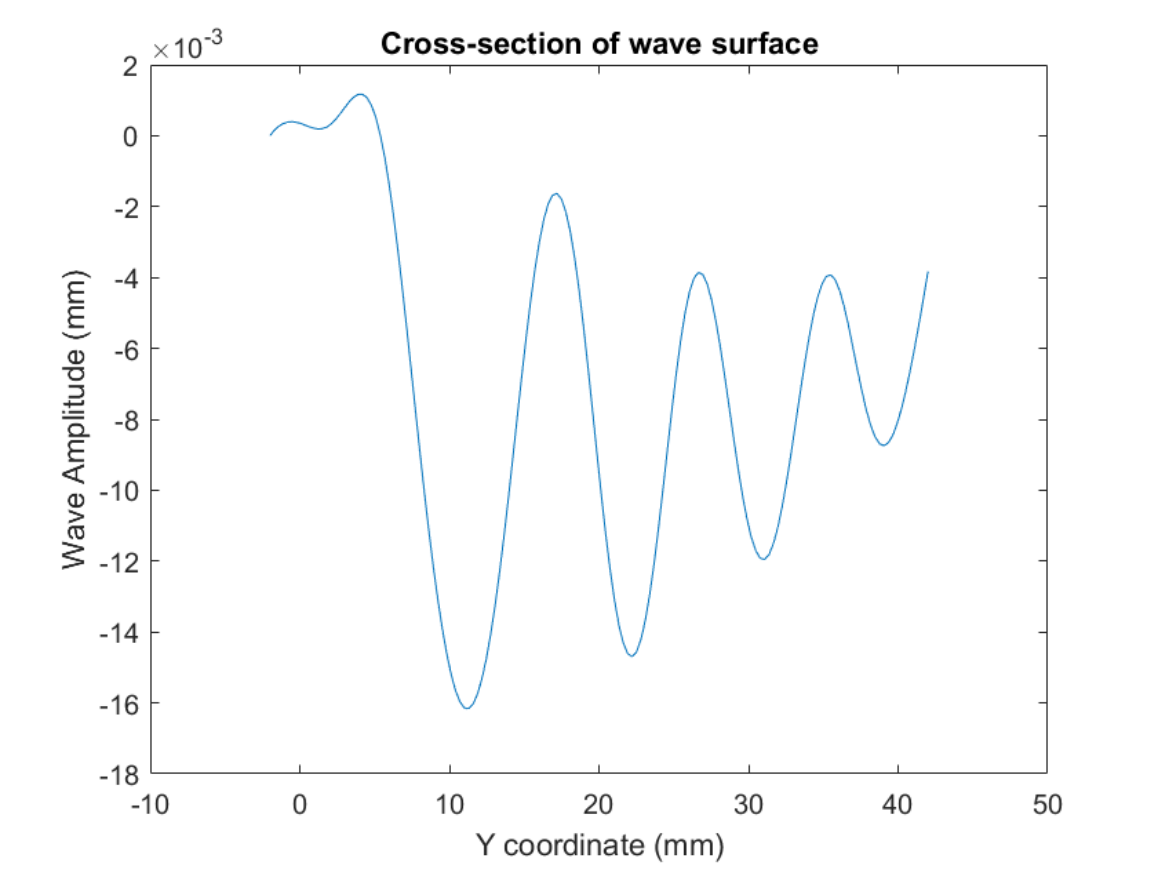
Inverse Ray-Tracing



Surface Normal



Cross-Section Reconstruction



Conclusion

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- Possible to measure tiny wave amplitude with simple setup
- Experimentation with crude setup is challenging, time consuming but exciting
- Need to perform quantification of sensitivity since initial study suggests high sensitivity to the input parameters
- Inverse algorithm works well but needs few minutes to run per frame
- Need to make it faster before starting the temporal decay study for viscosity

Thank you!