
Flow Visualization and Characterization of Capillary Waves using a Novel Optical Method

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Outline

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- Background and motivation
- New optical method
- Experimental setup
- Results
- Conclusion

Background and Motivation

Liquid Properties

○ Surface tension



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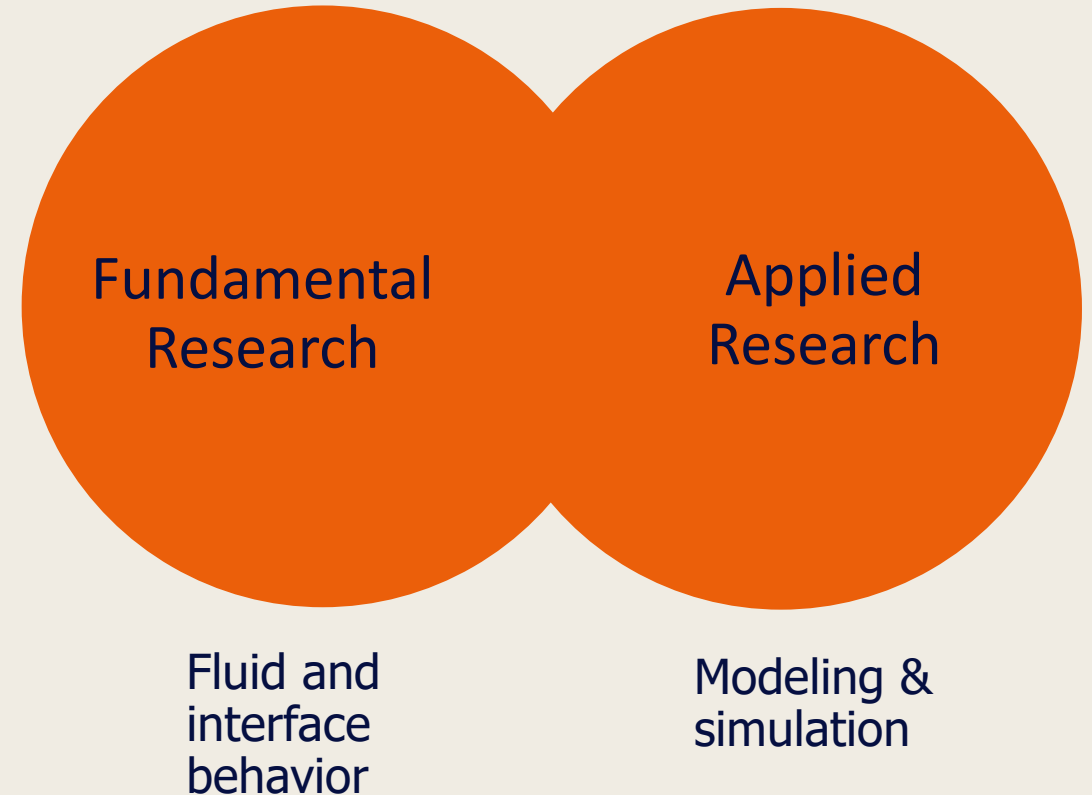
○ Viscosity



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Project Goal

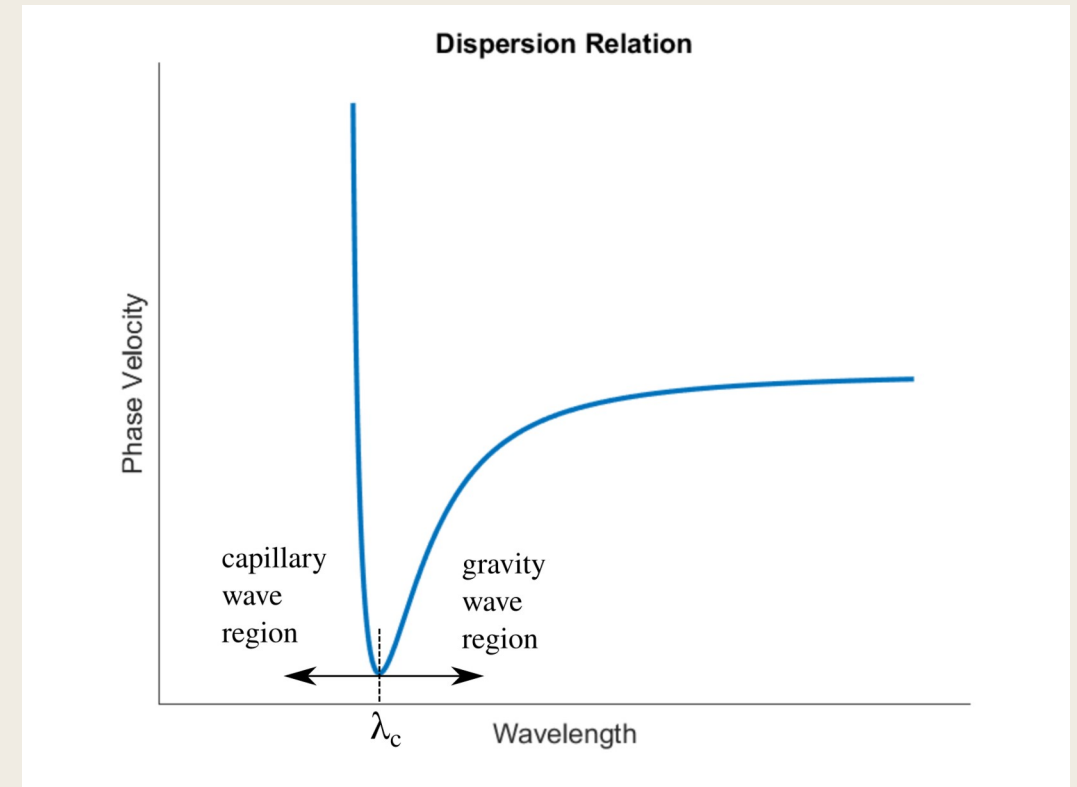
- Non-intrusive method for measurement of surface tension and viscosity
- Why?
 - Quantification of properties
 - Existing method
 - Applications
 - Chemical & process, energy, biomedical etc.
- Personal goals
 - Cheap, simple and mobile setup



Capillary Waves

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

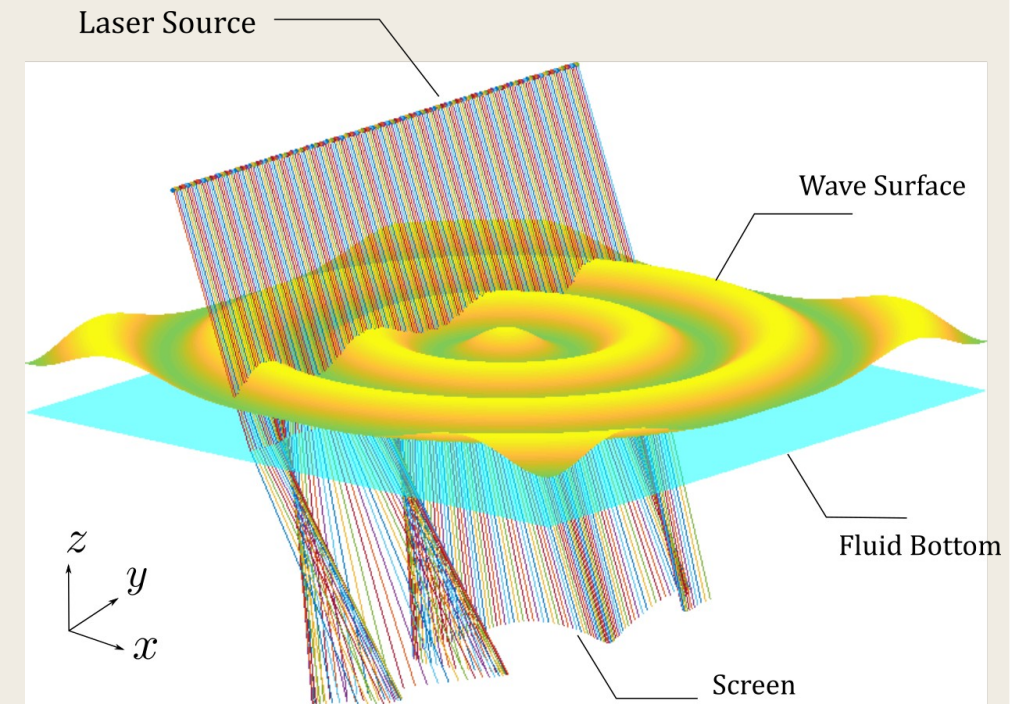
$$\omega^2 = k \left(g + \frac{k^2 \sigma}{\rho} \right) \tanh(kh)$$



New Optical Method

Numerical Validation

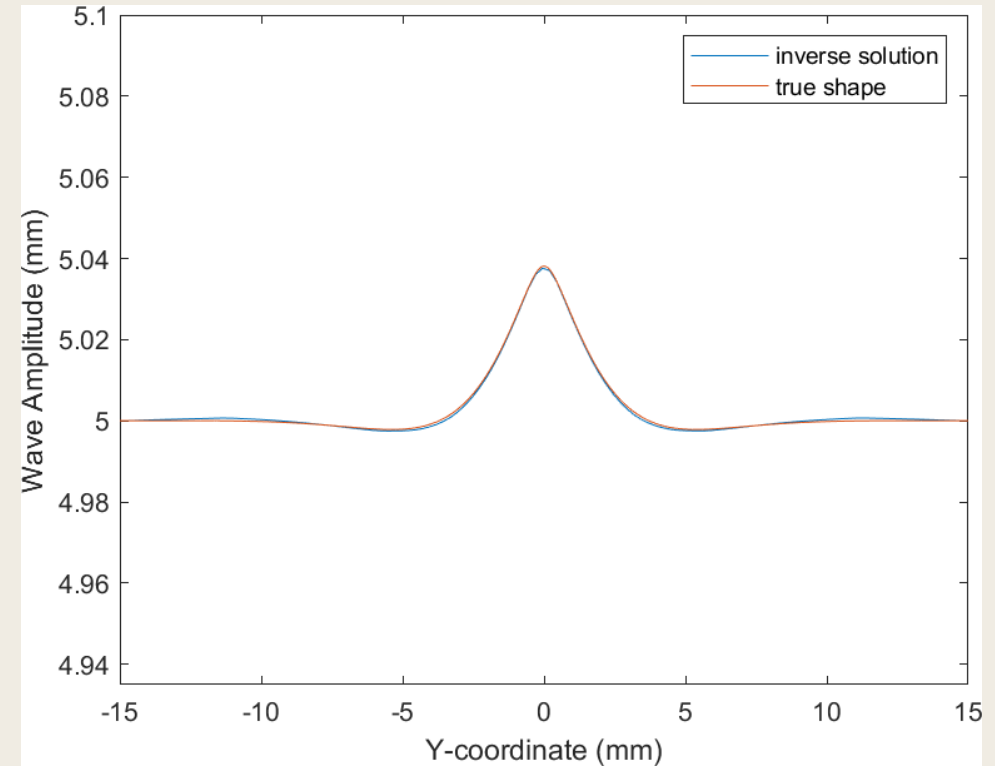
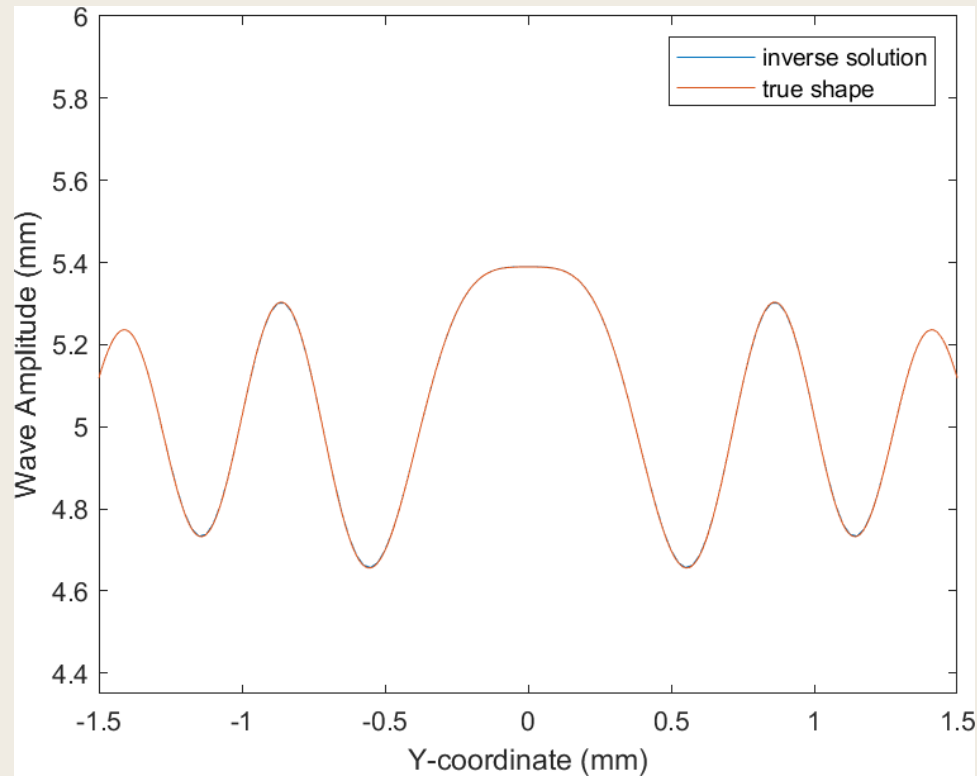
- Using refraction as magnifier
- Geometric optics
 - Forward ray-tracing problem
 - Inverse ray-tracing problem
- MATLAB code
 - Constrained and unconstrained numerical optimization



Mukim et al., AIP Advances, 2022

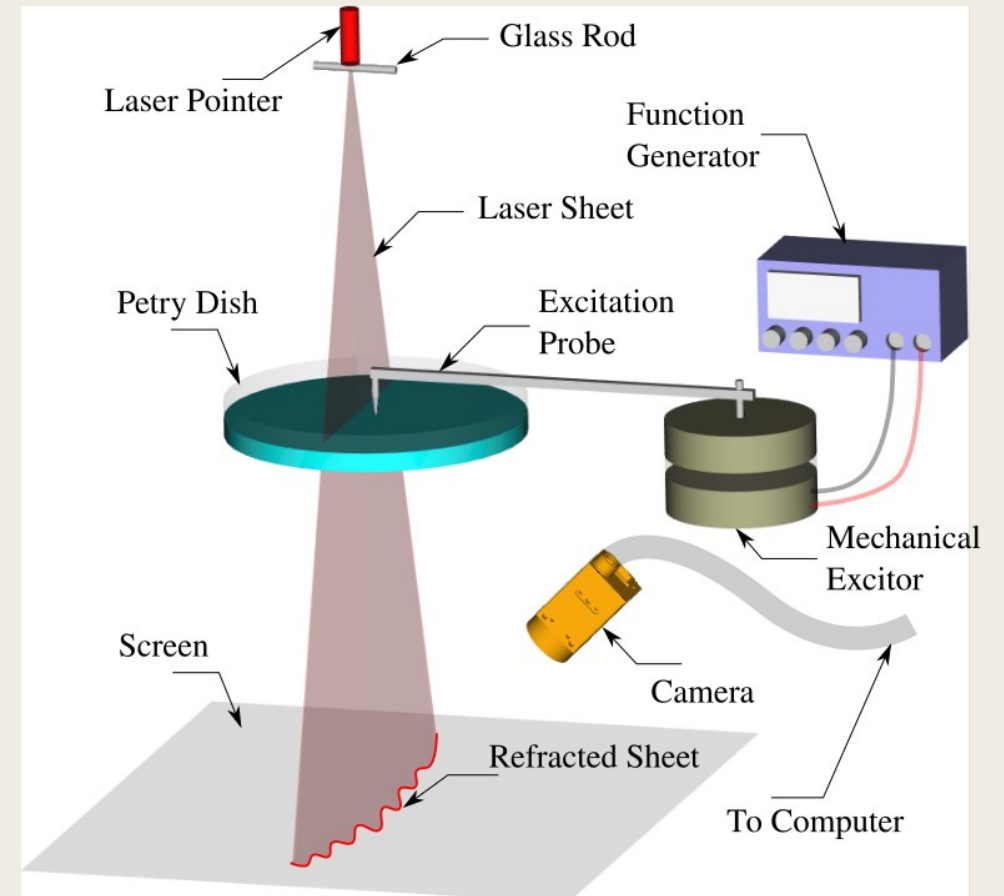
Numerical Validation

- Good accuracy for low and high curvature values



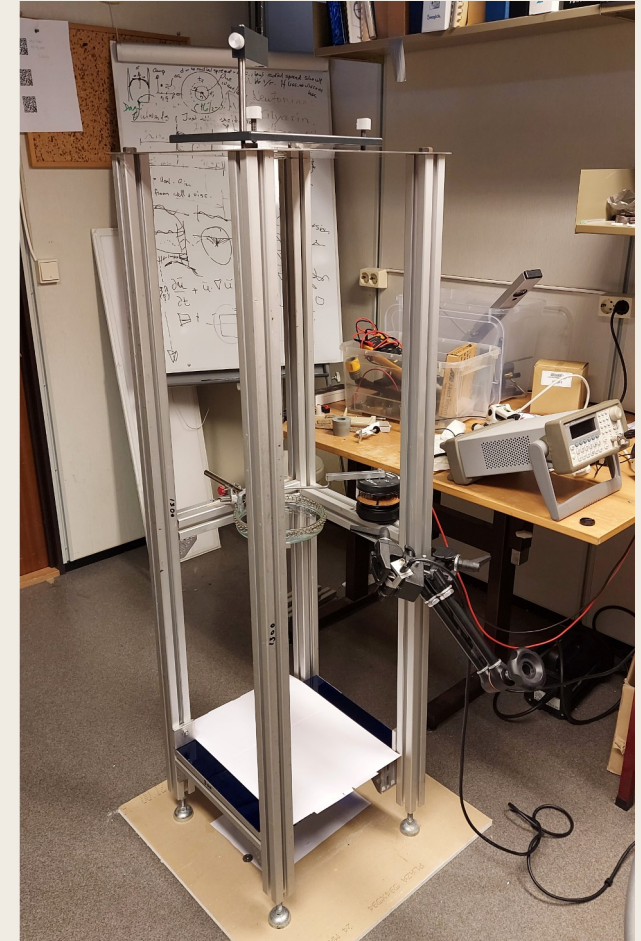
Experimental Setup

Proof of Concept



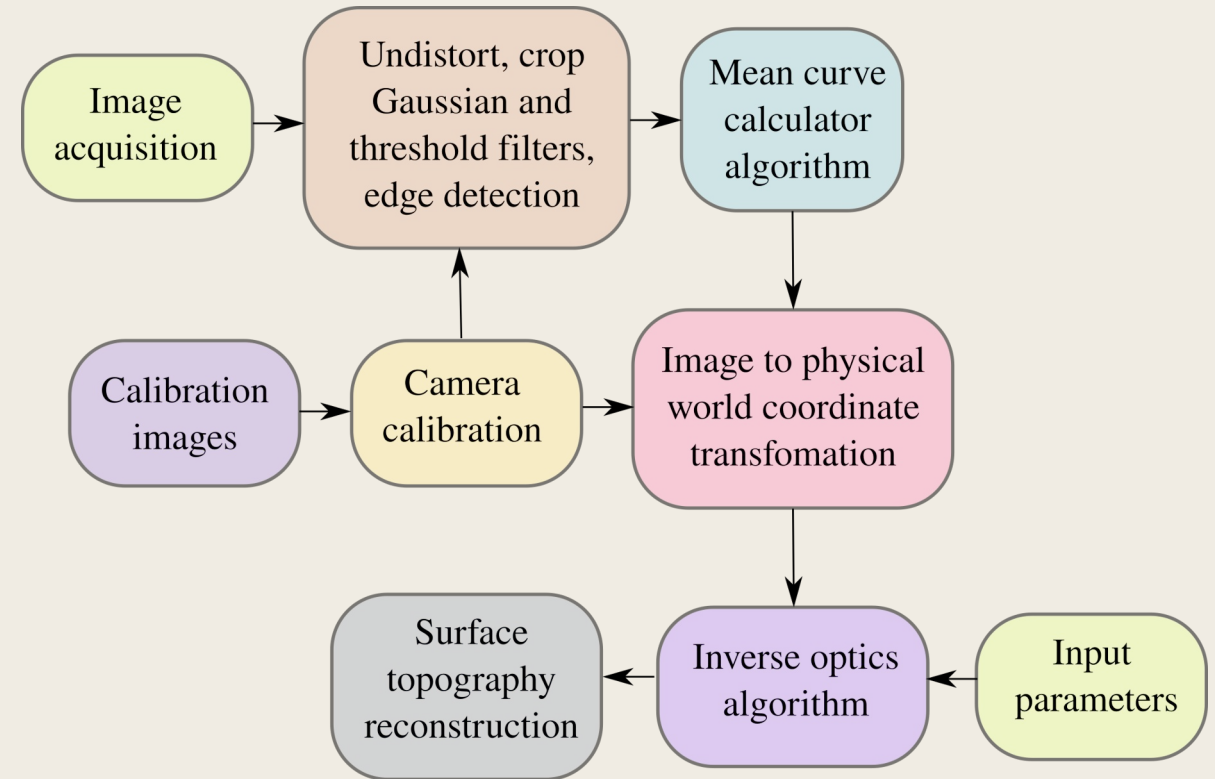
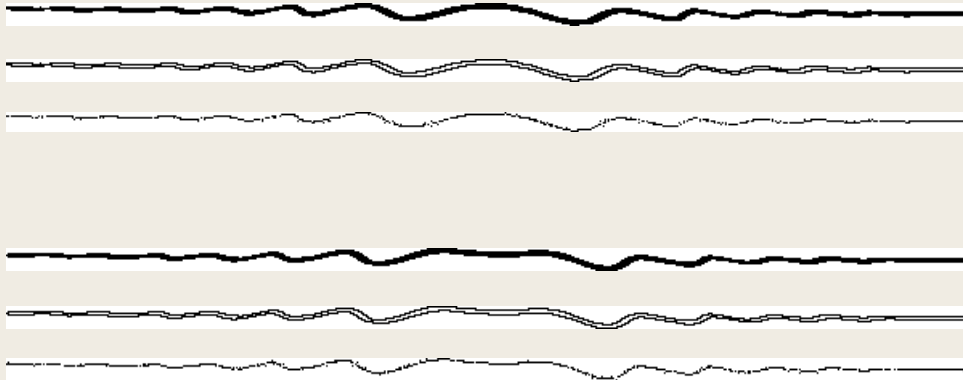
Setup

- Using things lying in lab to build simple setup
- 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
 - Inclusion of glass bottom



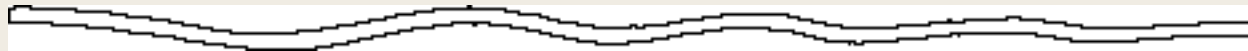
Post-processing

○ Mean Curve Calculation

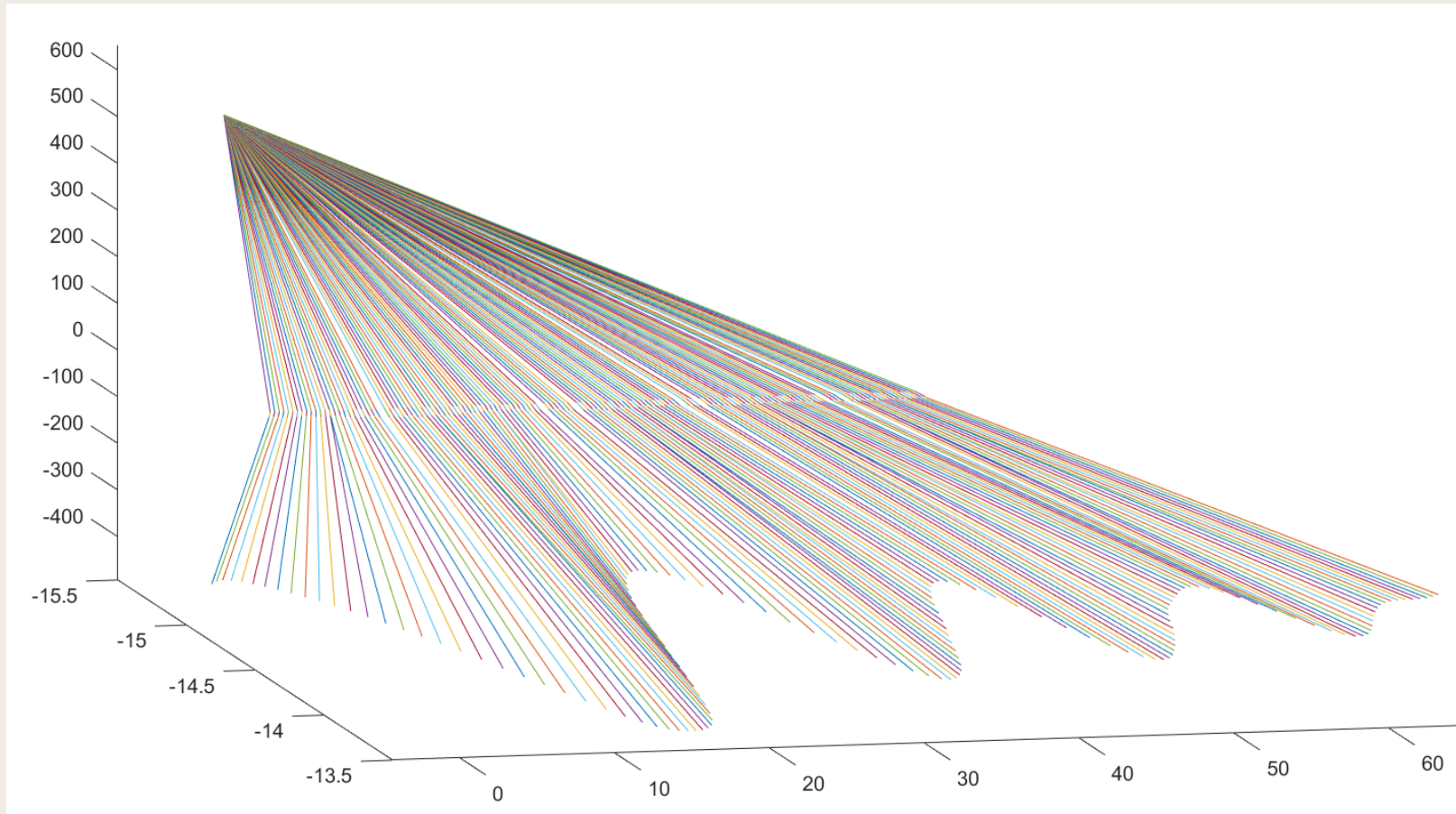


Results

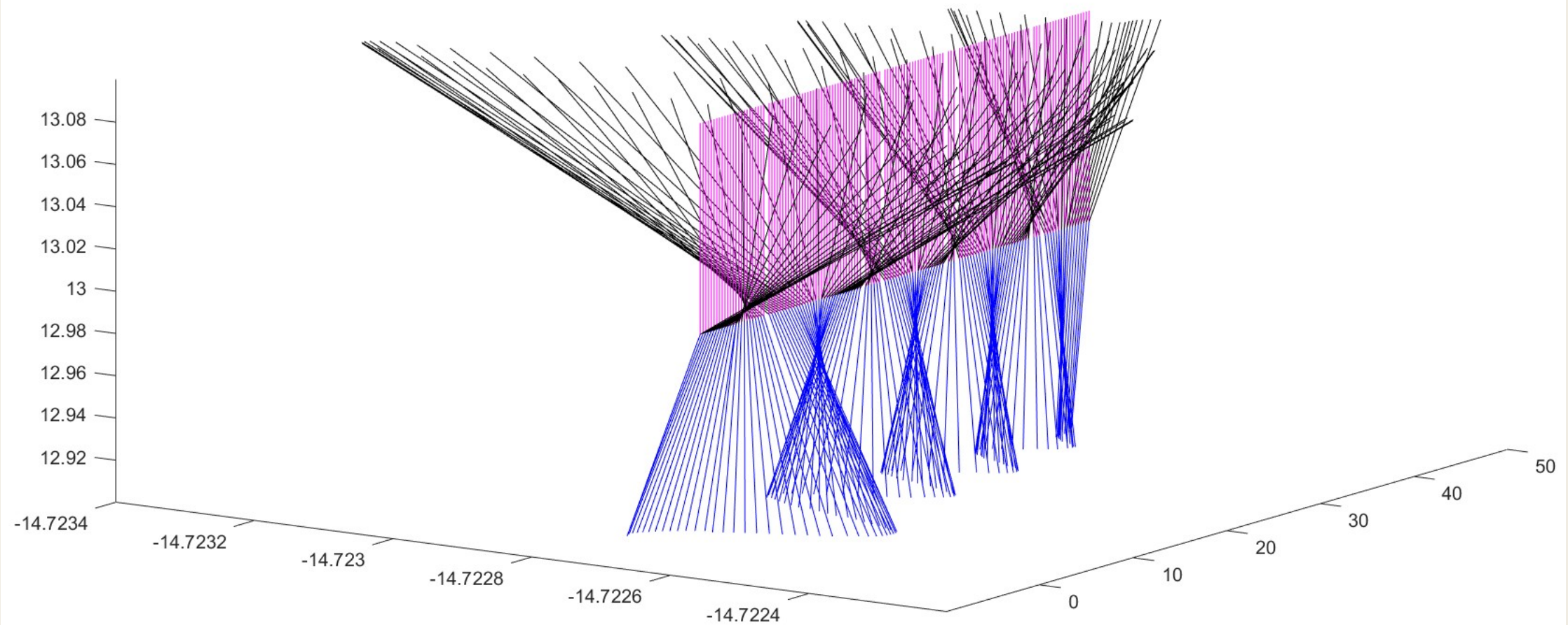
Image Processing



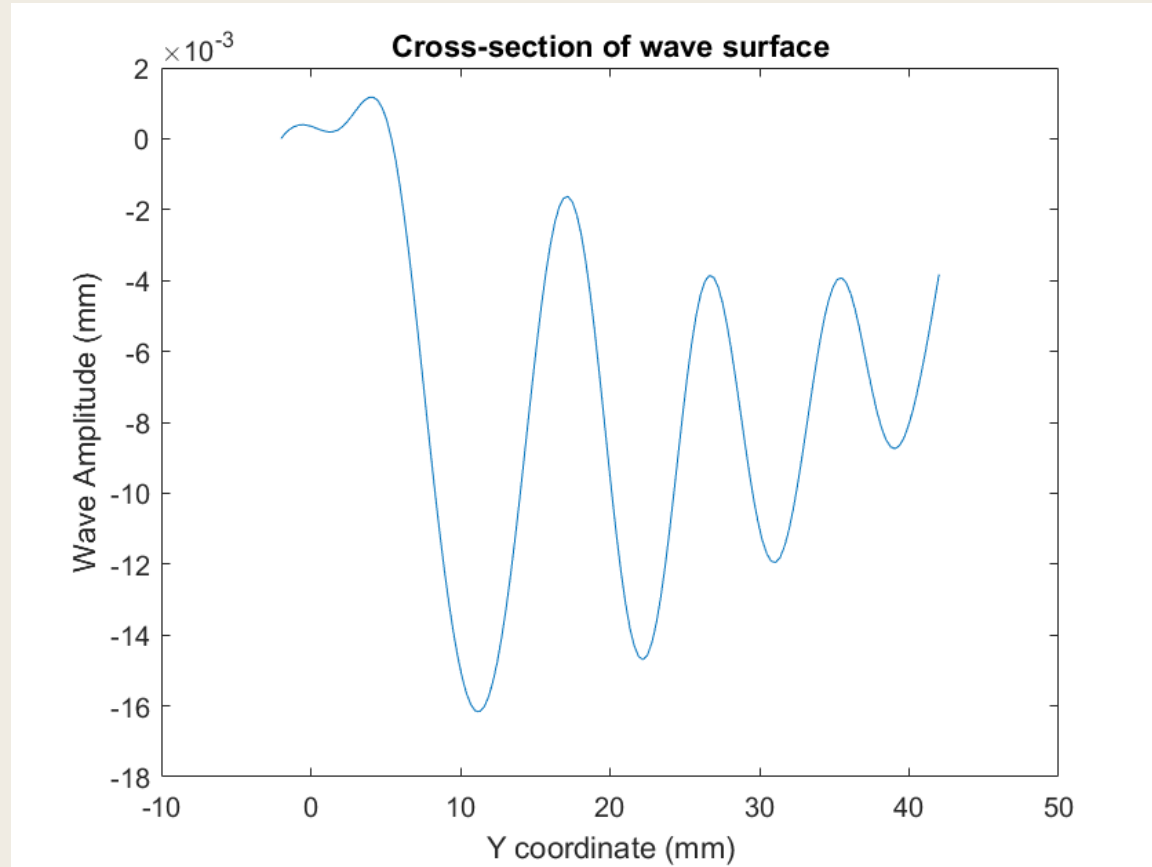
Inverse Ray Tracing



Surface Normal Calculation



Cross-Section Reconstruction



Conclusion

Conclusion

- Experimentation with crude setup is difficult, time consuming but exciting
- Possible to measure tiny wave amplitude with simple setup
- Results are promising but method needs a bit experimental and post-processing fine tuning
- 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 resolve this out before proceeding with temporal decay for viscosity

” Thank you!

