National Aeronautics and Space Administration

NASA

TECHNOLOGY SOLUTION

Optics

Fluid Lensing System for Imaging Underwater Environments

Next-generation sensing technologies for seeing through waves to explore ocean worlds

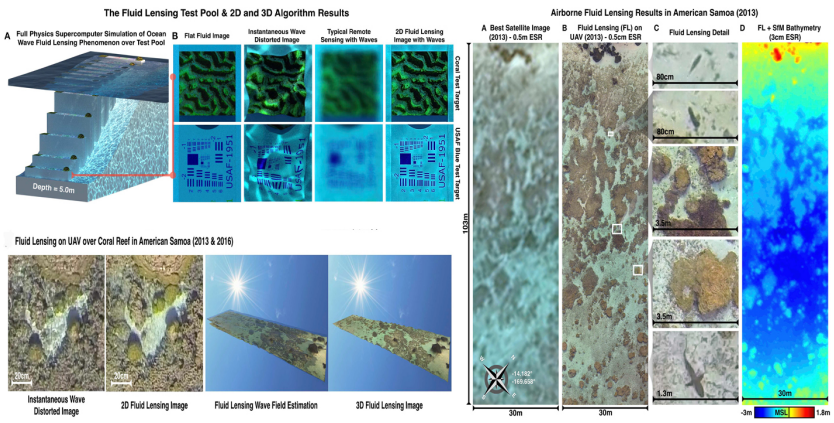
The optical interaction of light with fluids and aquatic surfaces is a complex phenomenon. At present, no remote sensing technologies can robustly image underwater objects at the cm-scale or finer due to surface wave distortion and the strong attenuation of light in the water column. As a consequence, our ability to accurately assess the status and health of shallow marine ecosystems, such as coral and stromatolite reefs, is severely impaired. NASA Ames has developed a first of its kind remote sensing technology capable of imaging through ocean waves in 3D at sub-cm resolutions. The patented breakthrough Fluid Lensing technology leverages optofluidic interactions, computational imaging, and fluid models to remove optical distortions and significantly enhance the angular resolution of an otherwise underpowered optical system.

BENEFITS

- Addresses the surface wavedistortion and optical absorption challenges posed by aquatic remote sensing
- Exploits surface waves as magnifying optical lensing elements, or fluid lensing lenslets, to enhance the spatial resolution and signal-to-noise properties of remote sensing instruments
- Enables robust imaging (at sub-cm-scale spatial resolutions) of underwater objects through refractive distortions from surface waves at sub-cm-scales
- Estimates fluid dynamics and optical coupling, compute image with enhanced angular resolution
- Processes high-frame-rate multi-spectral imagery with fluid distortion characterization and caustic Bathymetry Fluid Lensing algorithm
- Tested in a number of different environments for verification and proof of concept
- 3D Fluid Lensing Algorithm validated on FluidCam from aircraft at multiple altitudes in real-world aquatic systems at depths up to 10m
- Custom-designed and developed for airborne science and packaged into a 1.5U CubeSat form with space capable components and design

THE TECHNOLOGY

Fluid lensing exploits optofluidic lensing effects in two-fluid interfaces. When used in such interfaces, like air and water, coupled with computational imaging and a unique computer vision-processing pipeline, it not only removes strong optical distortions along the line of sight, but also significantly enhances the angular resolution and signal-to-noise ratio of an otherwise underpowered optical system. As high-frame-rate multi-spectral data are captured, fluid lensing software processes the data onboard and outputs a distortion-free 3D image of the benthic surface. This includes accounting for the way an object can look magnified or appear smaller than usual, depending on the shape of the wave passing over it, and for the increased brightness caused by caustics. By running complex calculations, the algorithm at the heart of fluid lensing technology is largely able to correct for these troublesome effects. The process introduces a fluid distortion characterization methodology, caustic bathymetry concepts, Fluid Lensing Lenslet Homography technique, and a 3D Airborne Fluid Lensing Algorithm as novel approaches for characterizing the aquatic surface wave field, modeling bathymetry using caustic phenomena, and robust high-resolution aquatic remote sensing. The formation of caustics by refractive lenslets is an important concept in the fluid lensing algorithm. The use of fluid lensing technology on drones is a novel means for 3D imaging of aquatic ecosystems from above the water's surface at the centimeter scale. Fluid lensing data are captured from low-altitude, cost-effective electric drones to achieve multi-spectral imagery and bathymetry models at the centimeter scale over regional areas. In addition, this breakthrough technology is developed for future in-space validation for remote sensing of shallow marine ecosystems from Low Earth Orbit (LEO). NASA's FluidCam instrument, developed for airborne and spaceborne remote sensing of aquatic systems, is a high-performance multi-spectral computational camera using Fluid lensing. The space-capable FluidCam instrument is robust and sturdy enough to collect data while mounted on an aircraft (including drones) over water.



Fluid lensing

APPLICATIONS

The technology has several potential applications:

- Marine industry
- Remote sensing missions
- sUAS-based science missions
- Science-based airborne and space-borne remote sensing
- Submerged asset imaging
- Marine debris

PUBLICATIONS

Patent No: 10,929,966

U.S. Patent Application Publication No. 2019/0266712

https://www.nasa.gov/ames/las/fluidcam-suas-imaging-system

Chirayath, Ved, and Alan Li. "Next-Generation Optical Sensing Technologies for Exploring Ocean Worlds-NASA FluidCam, MiDAR, and NeMO-Net." Frontiers in Marine Science 6 (2019): 521. https://doi.org/10.3389/fmars.2019.00521

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