A compact holographic microscope for atmospheric aerosol droplet/particle imaging as a secondary payload on the Picture-C balloon

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Objectives

Our overall objective is to develop and assemble a 3D digital holographic microscope with a large depth-of-field and volume-of-view that can be deployed on a terrestrial balloon in the future. Our specific goals here were to: 1) Design and fabricate an airflow control system to slow down the ambient airflow through our microscope's sample chamber during balloon ascent. 2) Define and select optical systems and cameras for operation in a balloon environment. 3) Carry out a thermal analysis for the cold temperatures expected in the stratosphere. 4) Define the laser driver and camera readout electronics based on previous field instruments. 5) Acquire all of the optomechanical and electronic parts called for by the design, and 6) Carry out initial instrument assembly. Our longer term objective is to complete system integration and test, and to deploy our system on a terrestrial balloon flight as a secondary payload to sample the atmosphere during ascent. .

Background

Interest in atmospheric aerosol droplets is on the rise due to the recent claim that liquid droplets may harbor life in the clouds of Venus. To characterize atmospheric particles by measuring their sizes, shapes, compositions and number densities in situ, volumetric microscopy techniques with roughly micron-scale resolution are needed. Moreover, a high instantaneous volume of view is necessary, as interesting (i.e.,potentially life-bearing) particles may be rare. Digital holographic microscopy (DHM) can meet these needs, as it can provide micron-scale resolution over an instantaneous volume of view approaching a cubic centimeter. Moreover, digital holographic microscopy provides both amplitude and phase images, as well as particle indices of refraction, allowing compositional discrimination between liquid droplets and mineral-based grains. Our aim was therefore to develop a large volume-of-view digital holographic microscope that could be deployed on a terrestrial balloon flight. This instrument could then serve as the starting point for a PICASSO proposal for the development of a Venus microscope instrument, potentially leading to a microscope package that could be flown on a future balloon in Venus's atmosphere.

Approach and Results

Our approach takes advantage our previous laboratory and fieldable digital holographic microscopes, which are largely built with low-cost commercial off-the-shelf (COTS) optics, cameras and single-board computers, along with software previously developed for these instruments. Specifically, the design of our balloon-borne DHM is based on a previous compact submersible microscope, the main difference being the external pressure. We thus began with a pressure re-design of the instrument housing and (optical and air-inlet) interfaces to the exterior, followed by the design of the interior mechanical, optical and electrical subsystems, and finally we carried out a thermal analysis of the system. One of our first major decision points was our selection of a dual-microscope design, which includes both a higher-resolution, lower volume-of-view DHM, and a separate lower-resolution, very-high volume-of-view lensless DHM. This requires two sets of optical windows and cameras, but as our selected operational mode will employ the two microscopes sequentially rather than concurrently, the control architechture remains fairly straightforward.

In detail, we 1) designed and built a simple airflow control system to slow down the ambient airflow (caused by the balloon rising through the ambient air) to be slow enough that atmospheric aerosol droplets could be imaged repeatedly and tracked across the volume of view, 2) selected the optics, lasers and cameras for both microscopes, 3) selected an operational approach with a low duty cycle of fast reads covering a few seconds once per minute during the balloon ascent, which enables non-simultaneous, i.e., sequential use of the two microscopes, 4) designed and selected the electronics subsystems and the single-board computer based on our previous submersible system, and 5) selected the data storage architechture to be fully on-board, with no downlinked telemetry, for simplicity and low cost. Finally, we also developed a thermal model for our system, which indicated that among other things, our system needed to include an outer radiation/heat shield (i.e., an awning) to isolate the instrument from direct sunlight.

One of the highlights of our work was the design of the airflow control system, for which we evaluated the options of filters, inverted nozzles and a "stop" box. Due to its simplicity, we selected the stop box approach, in which a small part of the outside flow is funneled through a small box surrounding the microscope's sample region, which is repeatedly sealed off from the outside flow to stop the flow inside the sample box, where it can be observed for a few seconds. Observations of the air in the stop box are carried out for a few seconds once per minute, allowing regular sampling during ascent. A second highlight is the large depth of field and volume of view achieved with our lensless design. Using a detector format consisting of a 2048 x 2048 array of 3.5 micron pixels, laboratory experiments showed the detection of water vapor droplets emerging from a humidifier at depths across the full gap between the instrument's pointlike (laser) light source to the detector array housing. This provides a roughly centimeter-sized depth of field for viewing, four orders of magnitude larger than the micron-scale depth of field of a conventional microscope.

Significance/Benefits to JPL and NASA

Our DHM will provide imaging measurements of the atmospheric particles that pass through the two DHMs during the balloon's ascent from the ground to its stratospheric float level. This will allow our microscopes to directly image and characterize the aerosol particles in our atmosphere, including measurements of particle sizes, shapes, indices of refraction, and number densities. This is important not only for characterizing the aerosols in our own atmosphere, but also for future space missions which will, e.g., aim at characterizing the aerosols present in the clouds of Venus. In particular, as it has been suggested that liquid droplets in Venus's atmosphere may harbor life, imaging characterization of Venus' cloud droplets are of great interest. Note that 3D microscopic imaging observations can enable the imaging of individual droplets in situ, without altering or collecting the particles, thus potentially allowing us to see any potential internal structure.

Publications: None yet

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