Probing micron-sized objects with photoacoustic sensing: Theory and applications

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The covid-19 respiratory illness resulting from the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has caused a worldwide pandemic over the past two years. Despite various screening methods, vaccinations, and mitigation methods, including masking and social distancing, covid-19 remains a global issue in part due to airborne viral transmission via aerosolization. Current screening methods have a slow response or lack sensitivity. In this study, we explore air-based photoacoustic spectroscopy as a rapid method to screen for the presence of covid-19 via viral RNA within aerosolized droplets.

Background – Transmission of covid-19 primarily occurs via airborne transmission through expelled aerosolized droplets from infected people [1]. Current methods to detect covid viral infections include reverse transcription-polymerase chain reaction (RT-PCR) and rapid antigen lateral flow tests (RAT) [2]. While these methods can confirm an infection, PCR is time-consuming to process, and RAT suffers from low sensitivity in addition to a 15-minute wait period. This study aims to develop a rapid screening system for the detection of viral RNA in aerosolized droplets using air-coupled photoacoustic spectroscopy [3] that can be used to screen people with immediate feedback (like a Breathalyzer), and monitor indoor air space.

We asked whether biological samples in the nanometre range could be sensed using photoacoustic sensing. This work explores whether aerosolized particles (micron size) containing viral particles (nanometre-sized) could be detected with photoacoustic sensing, using kHz ultrasound detection (to enable ultrasound propagation through air). We previously published on how micron-sized objects could be sized using photoacoustics (PA) and ultrasound (US) [4]. We derived simple analytical solutions to rapidly determine the US and PA signal power spectra minima and maxima, that could be used to identify the sample. We showed that using ultrasound frequencies above 100 MHz, the size of cells and cell nuclei could be determined.

Method – A syringe pump was used to push liquid from a 10 mL syringe through a nasal sprayer (Teleflex, USA) to create droplets in the 0.3-10 µm diameter range (figure 1). The liquid used in the syringe pump was water containing black dye (532 nm), acridine orange dye (Sigma, USA), or 50 nm gold nanoparticles (260 nm). The pump was turned on for 8 s while a laser (Radiant HD, Opotek, USA) collimated to a 1 mm beam diameter was aimed through the spray of droplets. Laser energies of 5 mJ (at 532 nm) and 3 mJ (at 260 nm) were used. The photoacoustic signals were detected by a 350 kHz planar ultrasound transducer (Ultran, USA), amplified by a 30 dB amplifier (RF Bay, USA), then

digitized by a Cobramax digitizer at 50 MS/s (Gage Applied, USA). The digitizer was triggered via the laser sync output.

Results – Initial tests using water droplets containing black dye with the 532 nm laser showed that photoacoustic signals were detected from droplets containing black dye, but no photoacoustic signals were detected from plain water droplets. This result demonstrates that air-coupled photoacoustic detection of particulates is possible despite the extremely high sound attenuation in air. The system was switched to a 260 nm laser wavelength and droplets containing acridine orange dye, which has an absorption peak at 270 nm, similar to DNA. Representative photoacoustic signals of plain water droplets and droplets containing acridine orange dye are shown in figure 2A. Generally, the photoacoustic signal amplitude of the orange dye was lower than that of plain water, despite a higher absorption coefficient. The photoacoustic signal amplitudes during the 8 s spray time are shown in figure 2B. As the orange dye concentration decreased, the average photoacoustic signal amplitude increased. The same procedure was then performed using droplets containing 50 nm gold nanoparticles and the 260 nm wavelength laser. The photoacoustic signal amplitude of droplets with plain water and nanoparticles at low, medium, and high concentrations over the 8 s acquisition duration are shown in figure 2C. The photoacoustic amplitude decreased with increasing nanoparticle concentration, the same trend observed with the orange dye.

To understand why the photoacoustic signal amplitude decreased with increasing absorber concentration, Monte Carlo simulations that calculated the photoacoustic signal amplitude from droplets containing varying levels of nanoparticle absorbers were performed. We found that the absorbers block light transmission near the droplet's surface, preventing photons from propagating deeper into the droplet. As the absorber concentration increased, fewer photons could reach the absorbers, resulting in a decreased photoacoustic signal.

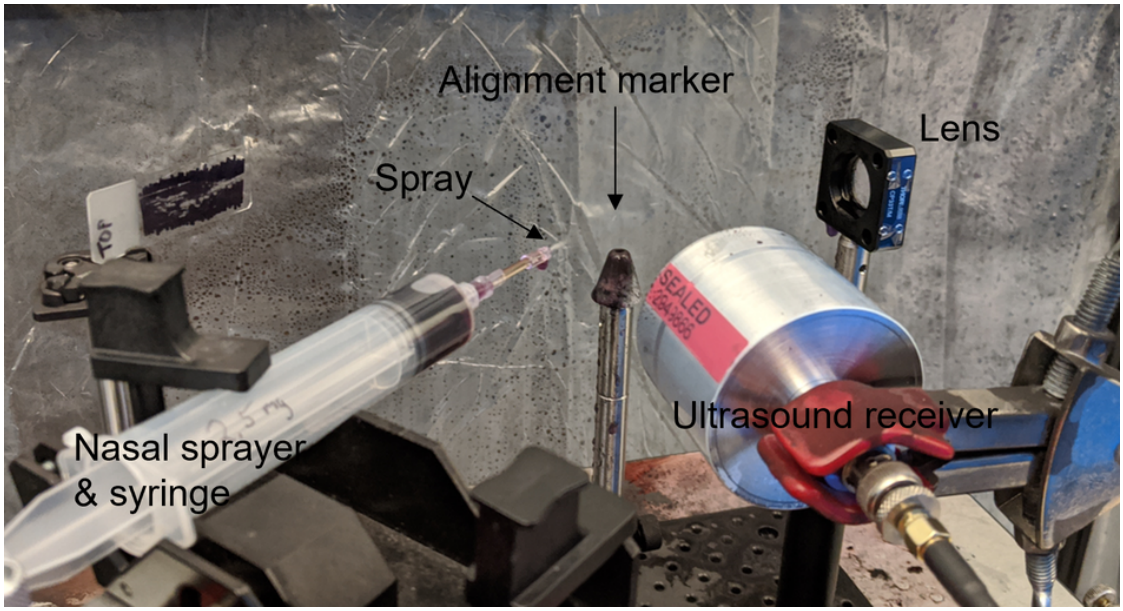

Fig. 1. The system setup to record photoacoustic signals from a droplet cloud.

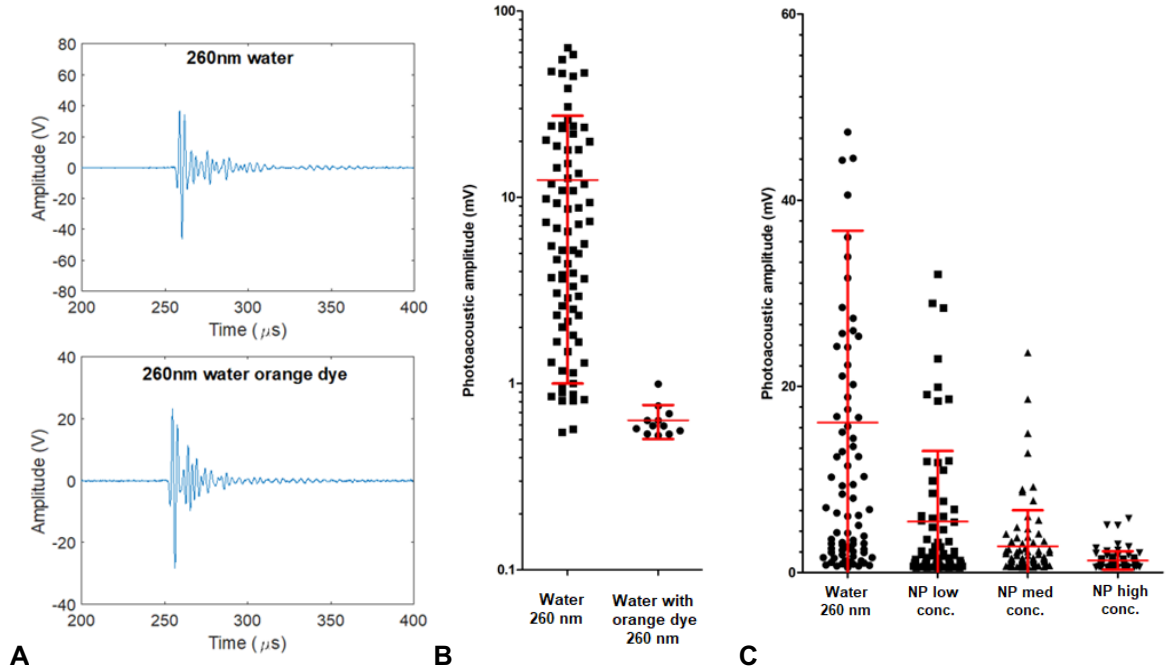

Fig. 2. (A) Representative photoacoustic signals from a droplet of plain water (top) and a droplet with acridine orange dye (bottom), **(B)** Photoacoustic signal amplitudes of droplets of water and water with orange dye recorded over 8 s acquisition, **(C)** Photoacoustic signals of droplets from water and water with nanoparticles at low, medium, and high concentrations.

Conclusion – This preliminary study suggests that air-coupled photoacoustics can be used to detect particulates in aerosolized droplets. The photoacoustic amplitude depends on the absorption and scattering properties of the particulates, where a decrease in signal amplitude with increasing absorber concentration was observed. Future work will use photoacoustic spectroscopy, where multiple wavelengths will be used to identify the particulates within droplets. Tests will be conducted using inactivated viruses to test the ability to detect viral RNA within aerosolized droplets.

References

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