# Always in focus

As the demand for sophisticated imaging systems grows, adaptive lenses with fast-focusing capability become indispensable. *Nature Photonics* spoke to Amir H. Hirsa from Rensselaer Polytechnic Institute about the oscillating liquid lens that he and his co-author have demonstrated.

**Tell me about the recent progress of liquid-lens technology.**
Fantastic feats have been achieved in making adaptive lenses, including arrays of liquid lenses, in part as a result of advances in microsystems, in particular microfluidics. For liquid lenses, one or more liquids are used to create an infinitely variable focal length without any moving solid parts by controlling the shape of the liquid's meniscus. Such lenses are attractive for adaptive-optics applications that require a fast response. The response time of conventional designs based on brute-force activation suffers, owing to liquid inertia and undesired transient motion. Advances in electrowetting have driven many of the advances in adaptive liquid lenses. The bottom line is that it is crucial to control the contact of liquids on solids and the implementation can be challenging.

**How are you able to achieve fast focusing?**
We explore the use of fluid dynamics and surface tension, in particular capillary phenomena that involve flow orthogonal to the gas/liquid interface. We report the experimental demonstration of a harmonically driven liquid lens with an oscillating focal length that can capture any image plane in a given range at the resonance of the oscillations. The lens features two droplets coupled through a cylindrical hole with pinned contact lines against a hydrophobic substrate. The change in the curvature of the droplets induces a change in focal length. The opposing curvature of the droplets creates a spring-like force that makes the system a natural oscillator. As image capture timing is electronic, it can be achieved rapidly, so the frequency response of the lens is only limited by its resonant frequency. We have achieved highly reliable imaging at over 100 Hz for a millimetre-scale liquid lens. Theoretical predictions tell us that a faster response is possible with smaller lenses, for example a 10-µm aperture lens can produce resonant frequencies as high as 100,000 Hz. However, length scales much smaller than that are not considered here because of the detrimental effects of viscosity.

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Amir H. Hirsa is confident that more and more devices will benefit from imaging using liquid lenses.

**Where did you get the idea?**
Inspiration, I would say, came when we first realized that our coupled droplets make excellent lenses. This serendipitous finding occurred when I was setting up a laser-induced fluorescence experiment with a light sheet to visualize and study the dynamics of a coupled-droplet system. As I looked down at the coupled droplets, which was just water with a few parts-per-million of a fluorescent dye, I saw a beam perfectly focused by a droplet. Once we recognized the potential of the coupled-droplet system in optics, fast control of the focal length was a natural avenue to explore. We found that under a wide range of conditions, the coupled-droplet system can be made to oscillate at resonance with little energy input and low pressure amplitude in the range of $10^{-6}$ to $10^{-4}$ atmospheres. When the oscillation is fast enough, the lens can be thought of as always very close in time to being at the desired focal length, and hence the idea of fast focusing behind this work.

**What is the physical mechanism behind your work?**
At a scale that is small enough so that gravity is not dominant, the coupled-droplet system with pinned contact lines balances fluid inertia against surface tension, and the system can be made to oscillate. The size of the droplets must not be so small that they are susceptible to viscous dissipation, and not too big as this introduces significant gravitational effects. From our experiments, we found that a millimetre-scale liquid lens is the right size.

**What are the applications?**
The coupled-droplet system with a pinned contact we have presented is a relatively simple idea that provides a new solution for imaging systems where fast changes in focal length are sought. We envisage that this concept can be applied to mobile phones, camcorders, and other small, light-weight consumer products with video-recording capabilities. The mobile phone is a particularly good example, where everything needed to activate this liquid lens is readily packaged, including a speaker that can provide the oscillatory driving pressure. Other interesting applications are autonomous, micro air vehicles for surveillance and defence, which would benefit from imaging capabilities in many directions rather than just good vision straight ahead or below. The relatively small size and the high energy efficiency of our lens suit the installation of many of these lenses in such a small vehicle to realize imaging at all angles at all times.

**What are the challenges for future work?**
One of the challenges is packaging, both in terms of the liquid lens, in particular evaporative losses, and the activation system. This is probably a technological rather than a scientific issue. Another technological challenge is the manufacture of liquid lenses using other substrate/liquid combinations. To paraphrase my co-author, Carlos Lopez, now the trick is to create a complete, off-the-shelf imaging system with the liquid lens.

*Interview by Rachel Won.*

*Hirsa and Lopez have a Letter on fast-focusing liquid lenses on page 610 of this issue.*