Mass-Market Imaging Systems Cut Time, Cost, Size

BY MARIE FREEBODY, CONTRIBUTING EDITOR

"Smaller," "cheaper" and "faster" seem to be the current buzzwords in the imaging industry – and some of the imaging components on the horizon may allow us to enjoy industrial capabilities in our everyday lives.

IMAGING TRENDS

Liquid lenses, 3-D mapping and cutting camera size are the three key trends in imaging this year. All three areas – at their various stages of maturity – are intrinsically linked, each serving the others in terms of performance, size and cost. And, as with many fields in photonics, as research progresses in one sector, the others can benefit also.

Liquid lenses shrink imaging systems

A liquid lens usually is composed of one or more liquids, which gives it remarkable tunability and flexibility. Scientists have long taken inspiration from nature for new design ideas, but John Rogers at the University of Illinois at Urbana-Champaign and researchers at Northwestern University in Evanston, Ill., have gone beyond the capabilities of nature with their "eyeball" camera. The curvilinear camera combines the advantages of the human eye with those of an expensive single-lens reflex camera and zoom lens.

Whereas earlier eyeball cameras had rigid detectors, this one's simple lens and photodetector are on flexible substrates and use a hydraulic system to change the shape of the substrate, enabling variable zoom. "Our work suggests that the 'flatland' world of existing digital imagers and CCD chips may no longer represent a design constraint," Rogers said.

The camera, which is described in the *Proceedings of the National Academy of Sciences* (doi:10.1073/pnas.1015440108), uses a tunable liquid lens to provide zoom magnification. The lens has an ultrasimple planoconvex design with a radius of curvature that is adjusted hydraulically. The curved detector is critically important to enabling high-performance imaging with such a simple tunable lens.

> "Cameras are ubiquitous, computing power keeps growing, and algorithms are being made available. This trend leads to robust solutions, which means more uses of the technology in more domains."
> –Gerard Medioni, UCLA

"The idea is that curvature in the photodetector array opens up a new engineering design space for digital cameras," Rogers said. "The result can be a dramatic reduction in the cost, size, weight and complexity of imaging lenses – which often dominate the size, cost and weight of a high-end camera."

The group has launched a startup company, mc10 in Cambridge, Mass., through which it is pursuing commercialization of stretchable optoelectronics, with hemispherical cameras as one product area.

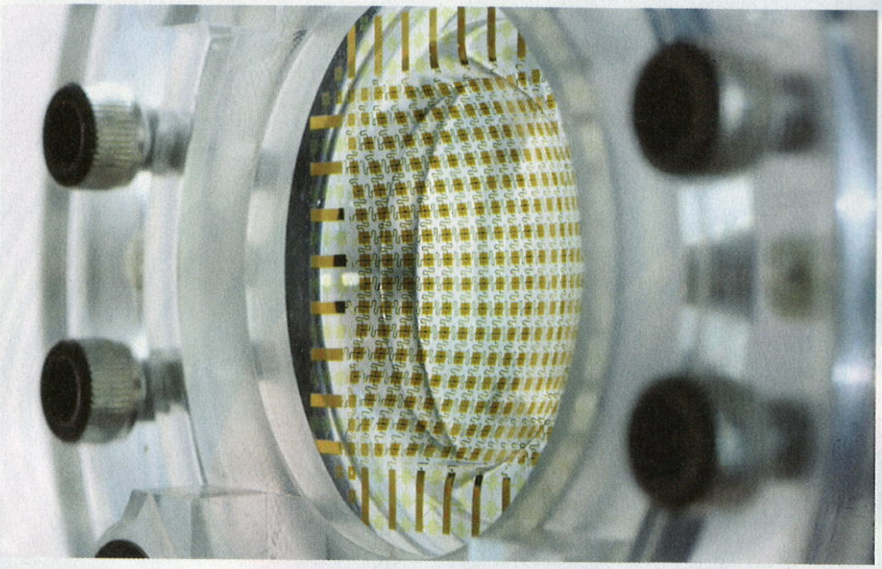
"We see the most promising, immediate applications in night vision, where the lenses are particularly difficult, and endoscopes, where size is critically important," Rogers said. "The hope is to establish the technology in these areas first, and then to move it into broader sectors of commercial use."

The goal is to provide "studio quality" imaging in small, low-cost devices that could, for example, be incorporated into a cell phone or an inexpensive digital camera.

Due to their inherent flexibility, liquid lenses offer capabilities that have yet to be exploited. Exploring some of these capabilities with the ultimate hope of commercializing them is the goal of a group at Rensselaer Polytechnic Institute (RPI) in Troy, N.Y.

Earlier last year, the team developed liquid pistons with oscillating droplets of ferrofluid that precisely displace a surrounding liquid (typically water) with an embedded lens liquid (in this case, 1-methylnaphthalene). The work was covered on Photonics.com (http://www.photonics.com/Article.aspx?AID=45462).

The lens is composed of a pair of droplets surrounded by another liquid that is driven by a set of nanoparticle-infused



The "eyeball" camera, built by John Rogers at the University of Illinois at Urbana-Champaign and researchers at Northwestern University, goes beyond nature. Courtesy of John Rogers.

ferrofluid droplets that can vibrate at high frequency, moving the focal distance of the lens under the application of an electromagnetic field.

Such lenses may provide a lighter-weight alternative to camera lenses and drivers, and perhaps could be used as replacement eye lenses that can be fine-tuned using magnets.

An important impact that liquid lenses will have on industry is the elimination of lens surface manufacturing, according to Amir H. Hirsa, a professor in RPI's Department of Mechanical, Aerospace and Nuclear Engineering.

"Ultimately, we hope that our approach to liquid lenses and similar ones will provide adaptability in a cost-effective, lightweight package," he said. "For example, we envision in situ assembly of lenses (self-assembly) for integrated devices that utilize lens arrays."

Some researchers are combining liquid lenses with other relatively new technologies. Take, for instance, Jannick Rolland, the Brian J. Thompson (endowed) Professor of Optical Engineering at the University of Rochester in NewYork, and invited professor at the Institute of Optics in Paris.

Rolland has produced some never-before-seen images by incorporating a liquid lens into optical coherence tomography (OCT) technology. The resulting handheld device can penetrate 1 mm into the skin to provide 3-D images of suspicious moles with the ultimate goal of eliminating the need for magnetic resonance imaging or biopsy.

"Fifteen percent of visits to primary care doctors are for the purpose of evaluating skin problems," Rolland said. "Assessment can be inaccurate, and microscopic evaluation in real time has the potential to significantly improve outcomes."

The idea was to place a lens based on immiscible fluids, produced by Varioptic SA of Lyon, France, in an otherwise conventional microscope. This was then manufactured by General Optics Asia in Pondicherry, India.

"This was the key to finally identifying and implementing a high-impact application for liquid lenses: having the ability to design a custom microscope that could accommodate this new technology internally, not externally," Rolland said. "This revolutionary step took a technology with very low intrinsic resolution and suddenly placed it as a key component in solving long-standing challenges in high-resolution imaging in both 2-D and 3-D within the medical and material industries."

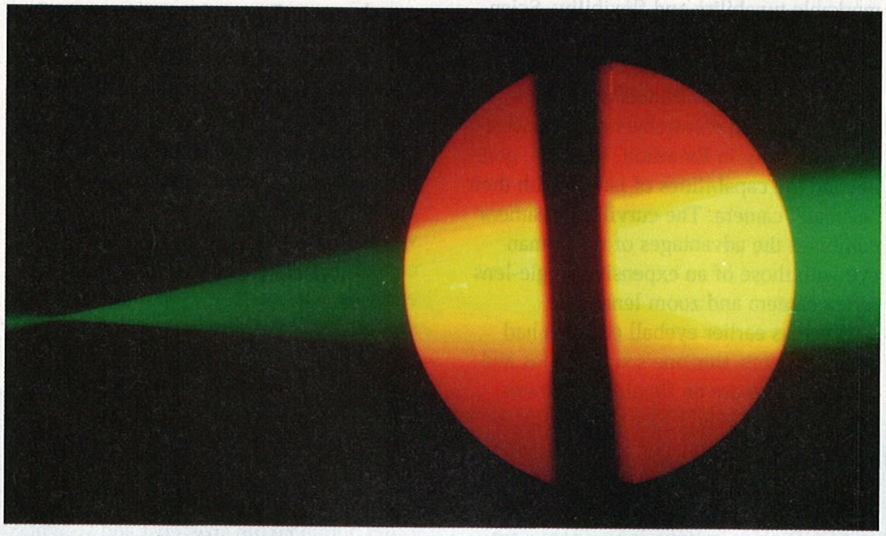
So far, the group has demonstrated in vivo imaging in skin at micron-scale resolution in a potential 8-mm^3 volume, and it has recently adapted its technology to imaging the cornea.

The primary challenge – a common one – is bringing down the cost of the entire OCT system: in this case, lowering the cost of a broadband laser. Rolland is in discussions with several companies, including Exalos, Genia Photonics, Micron Optics, NKT Photonics, Superlum, Toptica Photonics and Thorlabs, which are now working to meet the price-point target and bring the dramatic increases Rolland has seen in the laboratory to the clinic.

Apart from examining the skin, the device also can be applied to optical inspection of materials. Here, liquid lenses can help to reduce inspection time, thanks to their quick operation.

Rolland also has ventured into the use of liquid lenses in future 3-D optical head wear for virtual and augmented reality.

"A progression of prototypes developed over the past decade and a half is all converging to what could become our head wear of the future," she said. "The liquid lens may play a key role in our future head wear. Here, due to weight constraints, it will need to operate standalone, and so limiting diameter and speed



A 10-mm-aperture liquid lens with pinned contact lines focuses a laser beam. Liquid lenses can change their shape very quickly, enabling focal-length scans in excess of 30 Hz. Here the 1-methylnaphthalene lens and the surrounding water have fluorescent dyes for visualization. Courtesy of B.A. Malouin and A.H. Hirsa.