SUMMER 2009

Point of View
THE EYE RESEARCH INSTITUTE UNIVERSITY OF WISCONSIN–MADISON

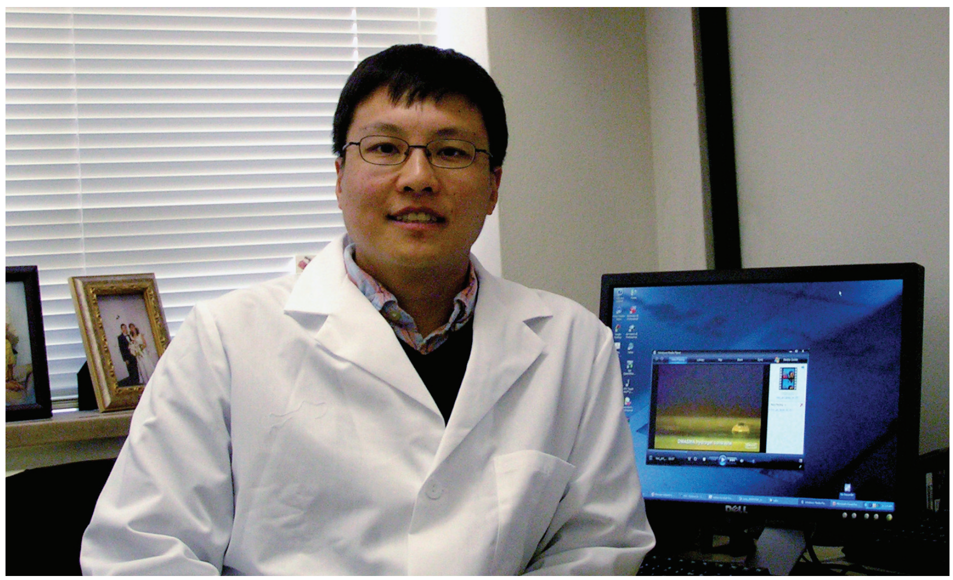
Taking Cues from Nature

Nature's inspiration — long evident in art, music, architecture, philosophy, and education — is increasingly apparent in science and engineering. Looking to nature's genius as the consummate problem-solver, researchers have modeled wind turbines on whale fins, a universal radio chip on the inner ear, and water-repellant fabrics and paint on the surface structure of the lotus leaf. Hongrui Jiang, PhD, seeks insight through understanding the remarkable models natural vision systems provide.

An associate professor in the department of Electrical and Computer Engineering and a member of the UW Eye Research Institute, Jiang believes that one of the most promising routes to designing lens technology — for optical imaging systems, medical diagnostics, surgical applications — lies in learning from nature. This concept of emulating nature's best biological ideas to address human problems, known as *biomimicry*, inspires much of his research. "I study natural visual systems in order to adapt or incorporate that knowledge into the development of artificial systems, trying to understand the delicate designs of nature and apply them for our benefit," Jiang explains. "There are no 'best' eyes in the animal kingdom — only those, after lengthy evolution, that are best suited to their owners, matched to their specific ecological niche."

Jiang's goal in engineering bio-inspired vision systems is not to replicate natural models, but to selectively incorporate the attributes of various vision systems into a superior system. For example, the dragonfly's compound eye, made up of thousands of *ommatidia* — visual units consisting of a lens system and a group of light sensitive cells — provides the insect with multiple viewing

Left: A dragonfly eye (photo by B. Krylov)
Right: Eyes of a jumping spider



Hongrui Jiang, PhD, is an associate professor of Electrical and Computer Engineering and an affiliate in the department of Biomedical Engineering and the Materials Science Program. His research interest lies in micro-electromechanical systems (MEMS), especially micro-optical imaging devices and systems for surgical tools.

angles and nearly 360-degree visual input. The jumping spider, with eight camera-type eyes ringing its head, uses its two forward-directed eyes for primary focus and its six secondary eyes to cover a wide periphery without expending energy to turn its head. The spider can also move the retinal structures within the eye to sharpen focus, but the lens remains fixed. Human eyes, by contrast, have a fixed retina and a lens that "accommodates," or changes optical power or focus through a change in curvature as the muscle fibers attached to the lens contract to alter its shape.

Integrating the various characteristics of these eye and lens types may advance effective image acquisition in biomedical contexts, or improve visual capabilities in surgical tools. Inspired by the human eye, Jiang and colleagues have pioneered a dynamic advance in artificial lens development, a liquid microlens termed "smart" due to its ability to vary focus in response to stimuli such as temperature, pH, or light.

"In response to the stimulus, an adaptable hydrogel ring expands or contracts around the water-oil droplet (microlens) it contains, shaping the liquid interface much like the ciliary muscles in a human eye regulate the curvature of the lens to change the focus," describes Jiang. Previously, microlenses were limited by their fixed focal lengths or required external controls to adjust focal length; but the sensing capabilities of these new stimuli-responsive hydrogels bypass the

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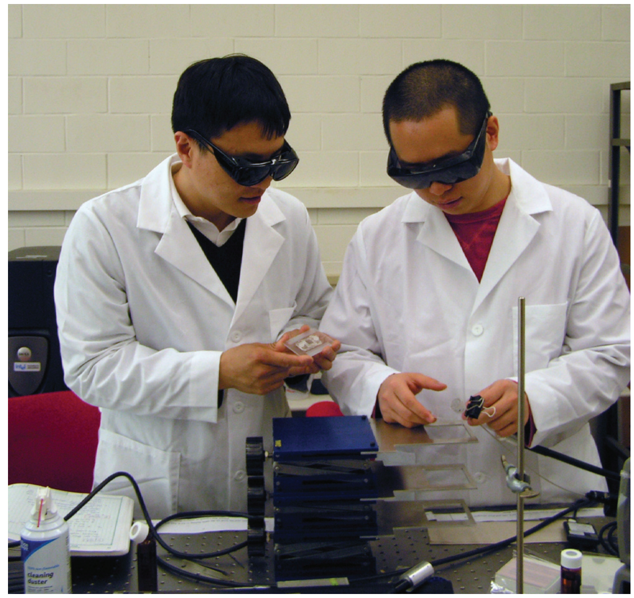
need for external control and detection systems and give these microlenses "intelligent" autonomous control.

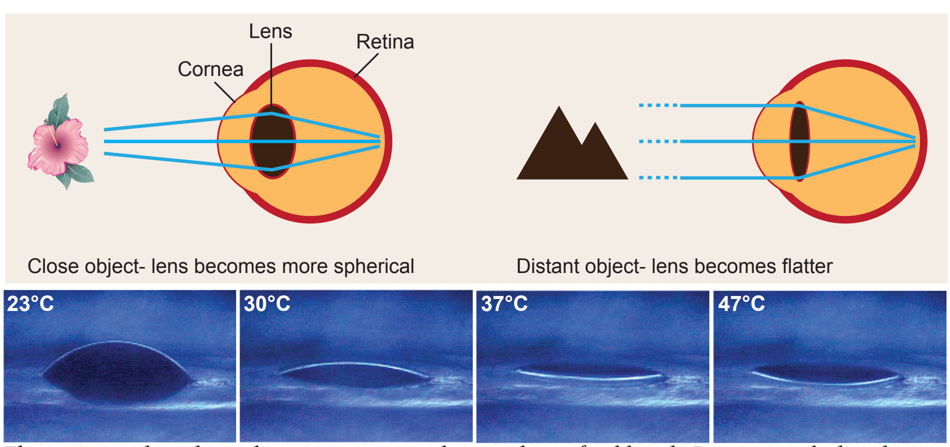
Placing such small smart lenses in instruments for laparoscopic or thoracoscopic surgery could free a surgeon's hands, eliminating the need to interrupt surgical procedures to manually re-focus. Using an infrared-light responsive hydrogel, Jiang has designed a prototype fiber endoscope with a "tunable" lens at its tip for focusing and scanning during endoscopic surgery. "The tunable lens allows change of focal plane, enabling sharp images of both close-up and broad internal target areas; a traditional non-tunable lens has a short focal length and must be very close to a surface in order to see," Jiang notes.

This variable-focus, tunable trait of the engineered microlens parallels the process of accommodation in the human lens. One of the common denominators of human aging, our diminished ability to focus on close objects, typically becomes apparent in our mid-40s, when we often need to hold reading materials farther away to see them clearly. With increasing age the lens in the eye becomes less able to adjust its shape to accommodate for near vision. This condition, presbyopia, is treated with corrective lenses (reading glasses or multifocal contact lenses) that require increased strengths and new prescriptions over time. Age-related cataract, a natural clouding of the normally clear lens, is a later stage in our lens aging process. Affecting nearly three-fourths of people over age 70, cataracts are treated by surgically removing the natural lens and implanting an artificial one in its place.


Hongrui Jiang and graduate student Xuefeng Zeng examine infrared-light responsive tunable liquid microlenses fabricated on a glass substrate, and prep a fiber optic cable to transmit infra-red light for testing the lenses.

Could a replacement lens be crafted to adjust focus and retain transparency, overcoming these faults of the aging eye? Jiang thinks that far-future ophthalmology applications may indeed include tunable lenses to correct presbyopia, or possibly intraocular tunable lenses to enhance visual acuity after cataract surgery. "But how to tune such lenses and how to determine focal length remain puzzling," he advises.

"Biological examples bear close examination, as we piece together the puzzles of their creative adaptations and apply them to new contexts," Jiang observes. He views the evolution of intelligent lens technology and artificial visual systems as collaborative opportunities, enhanced by the campus proximity of experts in engineering, computer sciences, visual sciences, ophthalmology, and optics. Noting that the UW environment encourages interdisciplinary efforts and respect for different approaches, Jiang comments, "Barriers between fields seem low, boundaries less distinct. With a specialist in every imaginable area, often within walking distance, I have great team resources." As proverbially two eyes are better than one, these multiple perspectives on learning from nature will continue to inspire new applications.



The top image shows how a human eye accommodates to change focal length. By contrast, the liquid microlens is tuned by varying temperature, thus changing focal length. Actual microlens size is 2.5 mm (~1/10 of an inch) in diameter.

The UW Eye Research Institute
445 Henry Mall #307
Madison, WI 53706
608/265–0690
email: info@vision.wisc.edu
website: vision.wisc.edu

Daniel M. Albert, MD, MS
Retina Research Foundation
Emmett A. Humble Distinguished Director

Arthur S. Polans, PhD
Associate Director

Tracy D. Perkins, MPH
Administrative Director/Editor