Toward mimicking biological vision with protein-based flexible imaging arrays

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A novel bioelectronic sensing device offers several potential advantages, including mechanical flexibility, and reduction in weight, power consumption, complexity, and fabrication cost.

Vision is the predominant sense for countless species because it provides the richest source of information about the surrounding environment. This is why researchers are striving to design artificial vision systems. In the field of mobile robotics, omnidirectional cameras have become increasingly prevalent due to their wide field of view. They also enable the development of more efficient algorithms for estimating optical flow. Unfortunately, their performance is often limited by the complex optics required to project scene points onto a planar CCD or CMOS array.

In contrast, biological vision systems feature simple optics schemes with photoreceptors arranged in very compact and nonplanar structures. Among vertebrates, the single-aperture eye has photoreceptors arranged along its inner concave surface, where a single lens focuses the light. The apposition compound eye, common to insects, has a microlens array that covers the convex surface of the eye. Each microlens focuses light on a small group of photoreceptors. In recent years, a number of artificial imaging sensors have been developed to mimic some of the features of these biological vision components. In most cases, novel microlenses and convex mirrors are being developed to interface existing image sensors.

Limitations in current silicon-based electronics have also prompted researchers to exploit the photosensitive properties of biological materials as a means of improving the functionality, performance, and fabrication of light-sensing and imaging devices.

With the goal of mimicking the shape of natural eyes, we have developed a new sensor array that exploits protein-based photocells and transparent flexible electrode technology. The protein in question is bacteriorhodopsin (bR), the light-harvesting system found in the cell membrane of Halobacterium salinarium. It exhibits photoresponse characteristics similar to those of the rhodopsin pigments that sense light in vertebrate eyes and has been the focus of intensive research for the past three decades.

Under anaerobic conditions, the bacterium grows purple membrane (PM) patches in the form of a two-dimensional crystalline lattice of uniformly oriented bR trimers. The PM uses solar energy to transport hydrogen ions across the bacterial cell membrane, thus generating the potential difference required to drive the synthesis of adenosine triphosphate. Its crystalline structure provides bR with a high level of chemical and thermal stability, making it an attractive material for developing artificial vision systems.

The most interesting property of reconstituted films containing uniformly oriented bR molecules is that they can gener-

Figure 1. Shown are diagrams of the top view and cross-section of a bacteriorhodopsin-based photocell array. The substrate is a thin film (blue) of PET with deposited ITO in a 4×4 pixel pattern (purple squares). PET: Polyethylene terephthalate. ITO: Indium-tin oxide.

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Figure 2. Shown is a 16-pixel bacteriorhodopsin photocell array on a flexible PET film.

Figure 3. This scan shows the differential photoelectric response (bottom) of a bacteriorhodopsin pixel to a step light signal (top).

Figure 4. The graph shows that illumination power and wavelength both affect the peak photoelectric response of a bacteriorhodopsin photocell.

To fully understand the behavior of bR-based sensing devices, we investigated their photoelectric response with a high input impedance and low noise amplification circuit. When exposed to light, our bR photocell readily demonstrated differential temporal filtering in its photoresponse (Figure 3). We believe that this attribute can be exploited to perform motion detection, edge detection, and contrast enhancement. Our results showed that the peak of the bR differential response varied linearly with changes in incident light power and wavelength. As shown in Figure 4, peak sensitivity occurred near 568nm. Other experimental results showed that the interpixel uniformity of this array was >71% of the average sensitivity value. We attributed the differences to variations in the fabrication procedure. We were also able to show that bending the array up to a 10mm radius resulted in minimal signal loss.

Depositing photosensitive biomaterials on inexpensive flexible electrodes will enable engineers to create innovative, lightweight, low-cost image-sensing systems. Our experimental results have shown that bR-based imaging arrays have great potential to be deformed into nonplanar geometries. Future research will be focused on creating bR-ITO-PET imaging arrays on hemispherical or spherical surfaces to investigate their information processing capabilities.

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