Bio-inspired hemispherical digital cameras of wide-angle field of view

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Bioinspiration or biomimetics[1] is the study of the structure and function of biological systems in nature for the designing and engineering of materials, devices and machines. Biomimetics can offer new potential and challenges for designing devices and machines with new capabilities by simply replicating nature.

It is important to understand the operational principle of light-sensing organs in biological systems in nature for the development of sophisticated digital cameras with improved resolution. Evolution has created highly sophisticated imaging systems with a wide-angle of view, low aberrations, an infinite depth of field in the compound eyes of arthropods such as ants, flies and bugs. In all modern cameras, the light reflected from any object is collected by a single lens and projected onto a single layer of light-sensitive material to form a sharp image. Human eyes as well as eyes of all other vertebrates use this concept of image formation with maximum light sensitivity and high spatial resolution. However, most living organisms possess compound or faceted eyes. Faceted eyes are composed of hundred or thousands of optical units commonly known as 'facets'[2]. In case of 'apposition' eyes of day-light insects, each facet is optically isolated from its neighbours and equipped with its own lens and photoreceptor. The light sensitivity of apposition eyes is very low with limited spatial resolution. However, the apposition eyes of insects can provide an infinite depth of field without adjusting the focal length of individual lens. The principle of light-sensing and imaging in arthropods is based on the concept of compound designs, in which arrays of smaller eyes act together to provide image perception. Each small eye, known as an ommatidium, consists of a corneal lens, a crystalline cone and a light-sensitive organ at the base.

Inspired by the complex fly eye, an interdisciplinary team led by researchers at the University of Illinois at Urbana-Champaign and Northwestern University, USA had developed a hemispherical digital camera with nearly 200 tiny lenses, delivering exceptionally wide-angle field of view, low aberrations and sharp images. Their findings were published in the May 2 issue of *Nature*[3]. In this paper, John Rogers and his colleagues described a new and novel protocol for fabricating a hemispherical camera which can replicate the compound eyes of fire ants and bark beetles. The new device was almost fully hemispherical consisting of nearly 200 imaging elements, providing a 160-degree field of view. The camera combined elastomeric compound optical elements with deformable arrays of thin-film silicon photodetectors in co-integrated sheets that can be moulded into hemispherical shapes. The design of this biologically inspired artificial compound eye camera is based on the principles of mechanics with amalgamation of stretchable electronics and optics[4]. Mechanics is very important for the development of this bio-inspired digital camera. As both the elastomeric optical element and silicon photodetector arrays were fabricated at planar geometries and transformed to hemispherical shapes, very large strains were introduced into these arrays. Each microlens (imaging element) was placed on top of an elastomeric pedestal, and then integrated onto a continuous elastomeric sheet. The strains introduced in the elastomeric sheet cannot be effectively transferred into the microlens in this design, and the pedestals served as 'strain isolation' layer. For the silicon photodetector array, a mesh layout design of isolated photodetectors interconnected by serpentine metal bridges was used to guarantee maximal stretchability in the electronic system. Figure 1 illustrates the photograph of insect-inspired visual sensor designed by Song *et al.*[3] which resembles the apposition eye of a daylight insect both functionally and structurally. Figure 2 shows the schematic representations and images of various components of bio-inspired digital camera.

The researchers faced great difficulty to fabricate such systems, as all established camera technologies depend on bulk glass lenses and detectors constructed on the planar surfaces of silicon wafers which cannot be bent or flexed. A significant feature of the bioinspired fly eye camera was that integrated microlenses, photodetectors and electronics were incorporated on hemispherically curved surfaces. The fabrication started with electronics, detectors and lenses arrays formed on flat surfaces using

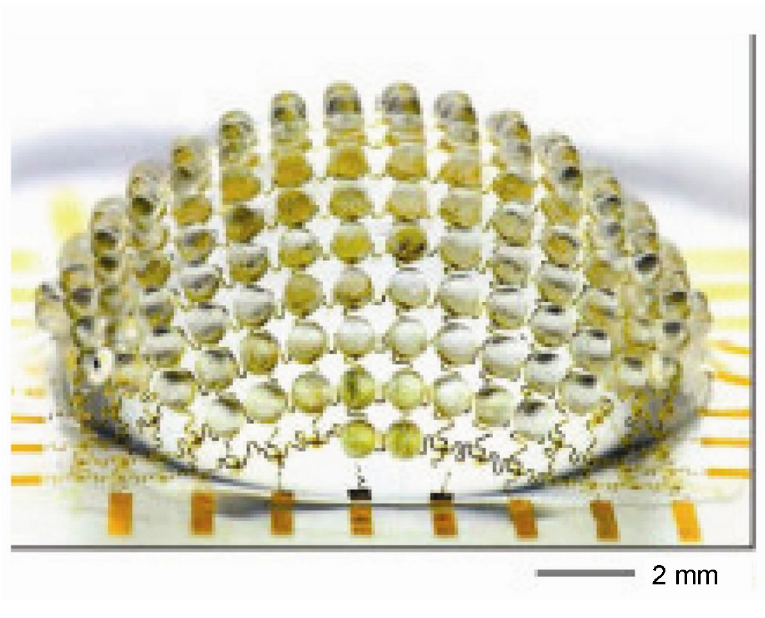

Figure 1. Image of the hemispherical microlens in the bio-inspired digital camera. (Reprinted with permission from Song *et al.*[1], Copyright (2013) Nature publishing group.)

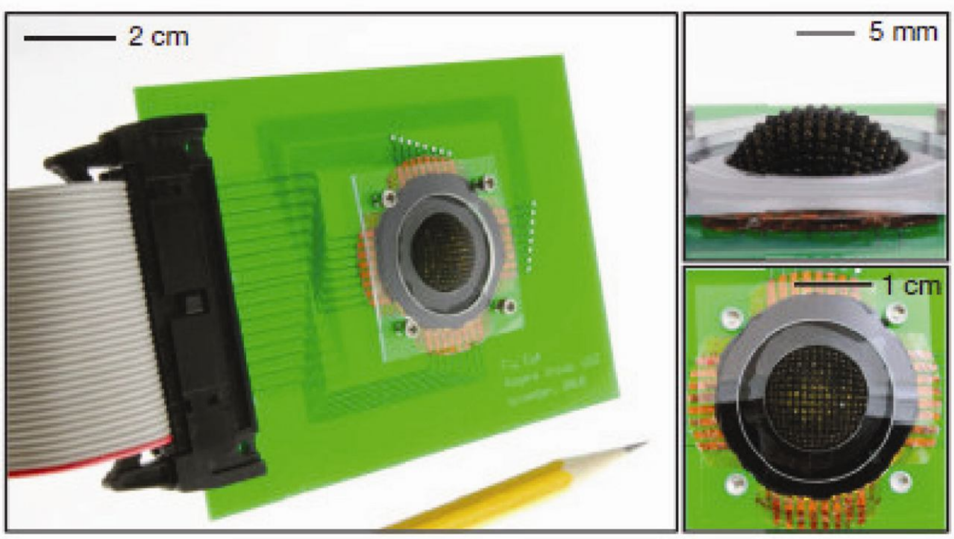

Figure 2. Photograph of the completed bio-inspired digital camera mounted on a printed circuit board. (Reprinted with permission from Song *et al.*[1], Copyright (2013) Nature publishing group.)

advanced techniques adapted from the semiconductor industry. The lens sheet was made from a polymer material similar to a contact lens and the electronics/detectors were allied and bonded together. Pneumatic pressure deformed the resulting system into the desired hemispherical shape through a process similar to blowing up a balloon, but with precised control. The individual electronic detector and microlens were coupled together to avoid any relative motion during this deformation process. In this case, the spaces between these artificial ommatidia can stretch to allow transformation in geometry from planar to hemispherical. The electrical interconnections were thin and narrow, in filamentary serpentine shapes; they will deform as tiny springs during the stretching process. According to the researchers, each microlens can produce a small image of an object with a form dictated by the parameters of the lens and the viewing angle. An individual detector will respond only if a portion of the image formed by the associated microlens overlaps the active area. The detectors stimulated in this way will produce a sampled image of the object that can be reconstructed using models of the optics. The 200 microlenses in this new fabricated camera can be compared with the compound eyes of fire ants and bark beetles.

It is expected that this bio-inspired digital cameras can be potentially applied ranging from advanced surveillance cameras to miniaturized tools for endoscopy in the near future.

1. Bar-Cohen, Y., *Bioinsp. Biomim.*, 2006, **1**, P1–P12.
2. Land, M. F. and Fernald, R. D., *Annu. Rev. Neurosci.*, 1992, **15**, 1–29.
3. Song, Y. M. *et al.*, *Nature*, 2013, **497**, 95–99.
4. Borst, A. and Plett, J., *Nature*, 2013, **497**, 47–48.

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