appaeared on 8th May 2013

The eyes have it

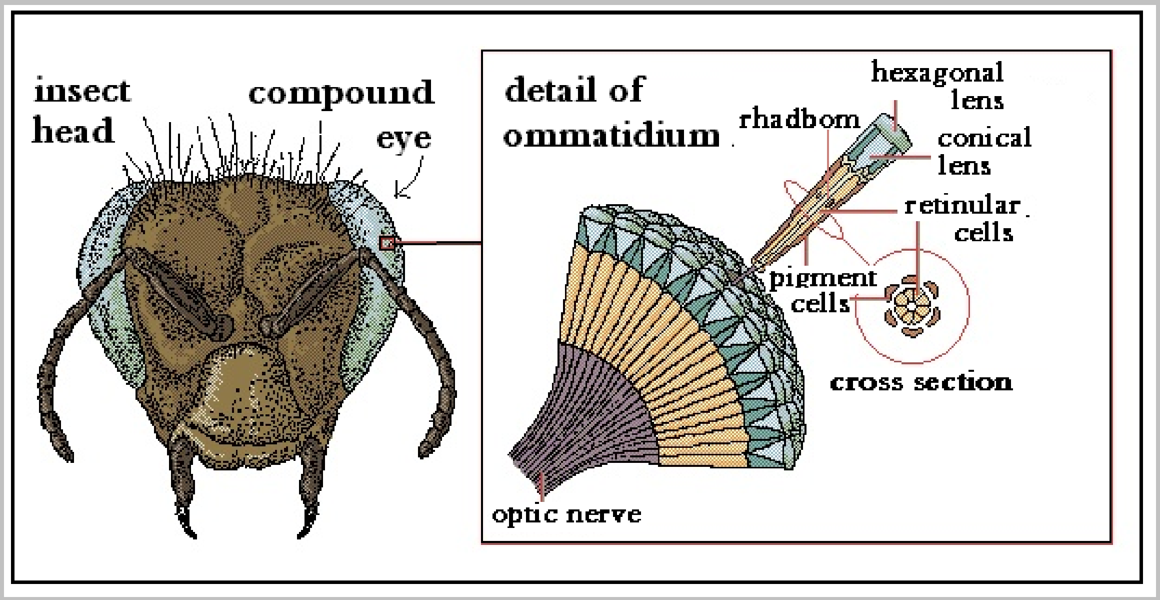
There is just more that meets the insects' eye, says S.Ananthanarayanan.

Who killed Cock Robin?
"I," said the sparrow, "with my bow and arrow."
Who saw him die?
"I," said the fly, "with my little eye."

But the little eye of the housefly is a remarkable instance of optical engineering. It is a ***compound eye***, consisting of thousands of separate optical sensors, each pointed at a slightly different angle, which gives the fly a nearly 180 degree field of view. And each sensor can detect many colours that we cannot see and also a feature of reflected light, called polarization, which helps the fly, the honey bee and many other species that have compound eyes, to see detail which is invisible to us. And compound eyes are highly sensitive to movement, as most of us must know if we have tried to swat a fly!

Young Min Song, Yizhu Xie, Viktor Malyarchuk, Jianliang Xiao, Inhwa Jung, Ki-Joong Choi, Zhuangjian Liu, Hyunsung Park, Chaofeng Lu, Rak-Hwan Kim, Rui Li, Kenneth B. Crozier, Yonggang Huang & John A. Rogers, working at institutes in Illinois, Harvard, Colorado, South Korea, Singapore and China, report in the journal, ***Nature***, that they have developed a laboratory, manmade copy, in function, complexity and size, of the insect eye.

The compound eye

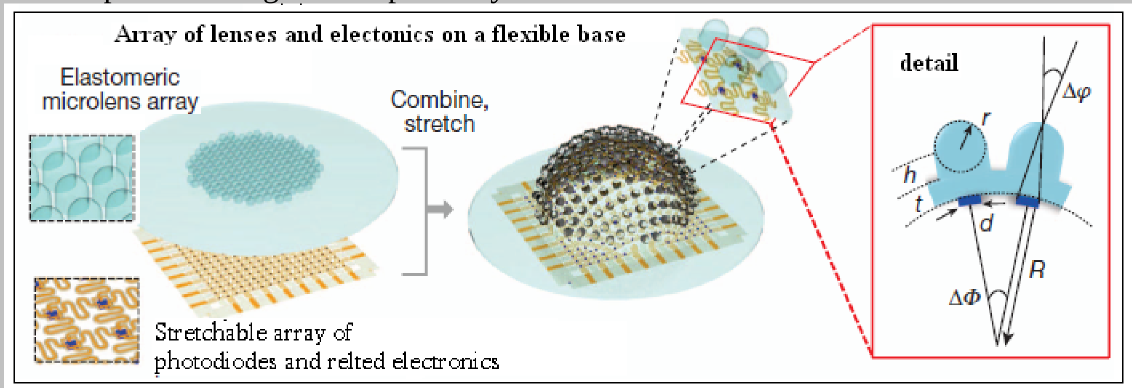


The eyes of insects and many other creatures with segmented bodies are compound, or made up of hundreds or thousands of separate visual units, which are called ***ommatidia***; The surface of the onnatidium is a hexagonal lens, below which is a conical lens, and the combination focuses a narrow beam of light on to a retina-like structure of light sensitive cells, called the ***rhadbom***. Pigment, or colouring cells separate the ommatidia and optic nerve fibres transmit the signal at each rhadbom separately to the brain.

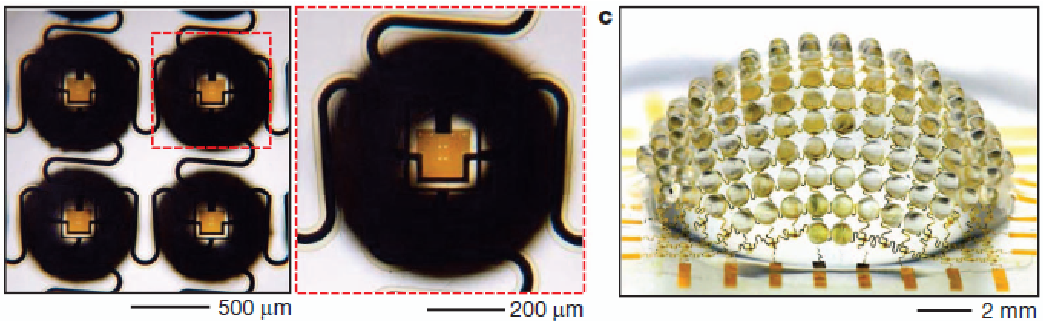
The ommatidia are placed in a nearly hemispherical form and hence cover almost the complete area before the eye. As each unit focuses at a narrow angle, there is no overlap and the images that are formed act like the pixels that make up the picture in print – the more in number the finer the detail, As the structures are at the cellular level, the insect eye has fairly good resolution even with the wide field of view. The other features are that as the lenses are of short focus, objects at all distances are in focus, which is to say there is good depth of field and the insect eye needs no muscles. And the eye is sensitive down to the ultra-violet. But the important feature is that movement of an object rapidly changes the ommatidia that are involved, and the eye is extremely sensitive to motion.

These features of compound eyes make it attractive to mimic the design in the laboratory, to create similar cameral lenses, for application in surveillance or endoscopy. The limiting factor has been the absence of technology of lenses and detectors that can be bent to form a curved shape, for wide coverage. The nearest approach has been with flat panels of compound lenses or curved shapes in large scale dimensions. Compact, full hemispherical shape with a good number of detectors has been out of reach.

In their paper in Nature, Young Min Song and colleagues have presented a scheme based on recent advances in flexible electronic components and hemispherical arrays of photo-detectors, which allow design features that were unachievable so far. Systematic experimental and theoretical studies of the mechanical and optical properties of working devices has led to a set of materials, layout and integration method for digital cameras which replicate biological compound eyes.



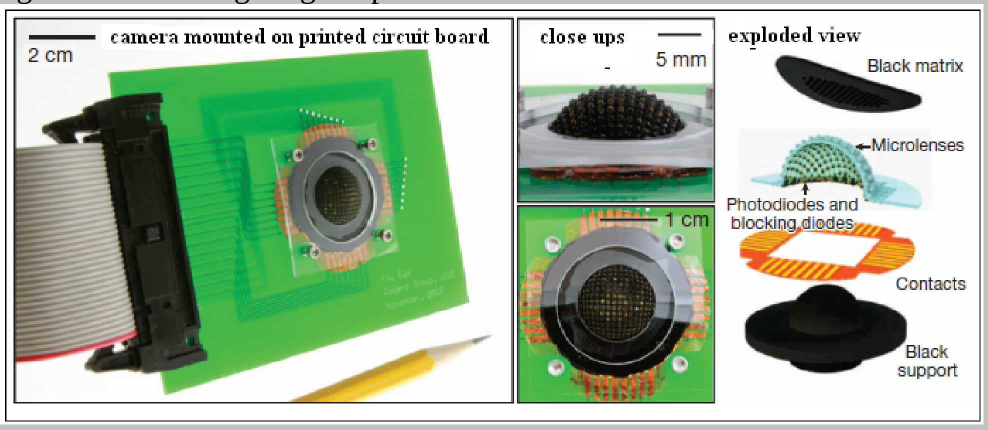
The three pictures explain how the arrangement works. The first is a moulded elastic sheet of a polymer, which acts like glass, and is shaped into 16x16 lenses. Of these 256 lenses, 180 participate in the camera and are mounted on matching cylindrical supports. The second subsystem is a matching array of silicon photo-detectors, provided with filaments of deposited metal conductors, to carry away the electrical signals when the detectors are activated. A key feature of the materials used is that it can be bent and stretched, to transform from a plane to a hemisphere. This kind of imager, shaped as a hemisphere, can then be mounted on further electronics for combining the images of the ommatidia to create the final, wide angle view. The picture shows that the hemispherical array of 180 detectors, which matches the design of the eye of fire ants or bark beetles, is less than 2 cm across.



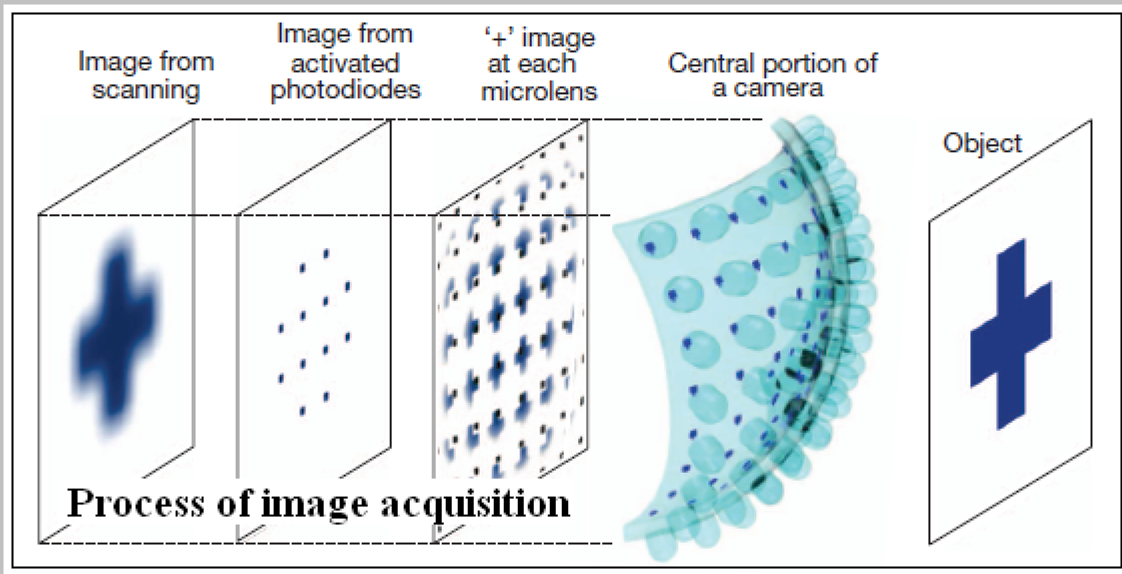
microscope picture of 4 adjecent ommatidia in a plane, with a magnified picture one of them

After deformation into hemisphere

Working cameras constructed in this way have been found to give excellent characteristics and high yields. Individual ommatidia form images of the object in view according to the angle from which light is incident. The photoreceptors are activated only if the image falls on the sensitive area. The photodiodes stimulated like this create a sampled image of the object, as is shown in the picture. In living things, there is rapid motion of the eye, or combination of the images of a moving object, that work to improve the resolution, or the level of detail. Similar effects were created and modeled by scanning the images of different ommatidia, to improve the images formed. Special software, computing algorithms and data acquisition methods help the camera adapt to changing conditions of lighting or speed of movement.



The key features, of being scalable to large numbers of ommatidia, different layouts and dimensions, and compatibility with silicon electronics suggest that commercial compound lens cameras could equal or better the biological templates by which they were inspired.



Process of image acquisition