Tech Notes

Orthogonal Transfer Array: Enabling wide-field imaging

Arrays of unique charge-coupled devices developed at Lincoln Laboratory are making it possible for the world's largest focal plane to image vaster expanses of the night sky than ever before.

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Scientists have always been curious about the myriad celestial bodies—planets both large and minor, asteroids, comets, and stars—in our galaxy and beyond. Could any of these bodies' behaviors impact the Earth and how? What might information about these objects reveal about the evolution of the solar system?

Study of these bodies is reliant on the ability of telescopes to capture images of the sky. Thanks to the orthogonal transfer array (OTA), an innovative technology jointly developed at MIT Lincoln Laboratory and the University of Hawaii, the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS), a wide-field imaging facility under development by the University of Hawaii's Institute for Astronomy, will be able to capture sharper images of a larger percentage of the night sky than any other existing system is able to capture.

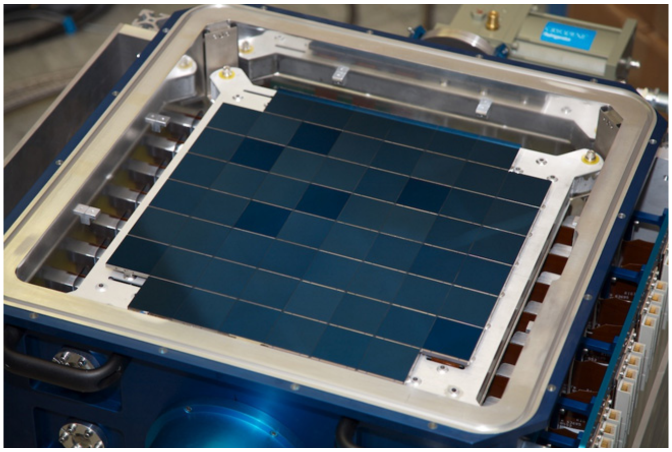
The prototype for the first of the four optical systems that will eventually make up the full Pan-STARRS is equipped with a 1.4-gigapixel focal-plane array (FPA), the world's largest and most advanced. This FPA will enable Pan-STARRS not only to image an extremely wide area of the sky since its field of view (FOV) is three degrees in diameter, or six times the diameter of the moon, but also to map the sky to great degrees of sensitivity, detecting stars that are 10 million times fainter than those observed by the naked eye.

The motion compensation problem

What sets Pan-STARRS apart from other wide-area astronomical imaging systems is its ability to compensate for atmospheric-induced jitter in the celestial images as well as for telescope shake and vibration. Traditional detectors used in astronomy cannot compensate for these effects. Fast steering or tip-tilt mirrors are sometimes used to stabilize the imagery at the focal plane, but these have serious drawbacks in terms of size, complexity, and speed. Moreover, tip-tilt mirrors can only apply a single correction uniformly across the FOV, whereas the image jitter from atmospheric effects varies over small angular distances.

To solve this problem, researchers at Lincoln Laboratory and the University of Hawaii developed the OTA, a new detector that uses an array of orthogonal-transfer charge-coupled devices (OTCCD) to compensate electronically for image motion at the pixel level.

In a traditional CCD, an image is acquired in the form of charge packets generated by light falling on the pixels in the CCD. After acquisition, these



The Pan-STARRS focal plane array contains 60 orthogonal transfer arrays, comprising about 1.4 billion pixels in the 16 in^2 area. Photograph courtesy of John Tonry, University of Hawaii.

Both of these images were taken with a spring-mounted, OTCCD–equipped camera that was bouncing. The image on the left was obtained with the OTCCD feature disabled and shows the blurring caused by the motion of the image across the device. Contrast this to the image on the right obtained with the feature enabled; the charge moved in synchronization with the motion across the imager, resulting in the improved clarity.

packets are shifted pixel by pixel to the periphery of the chip, where they are detected. A conventional CCD is limited in that it can shift the pixels in only one direction. The OTCCD, on the other hand, can be programmed to shift packets in any desired direction. Consequently, if the scene moves across the pixels during image acquisition, the packets can be shifted synchronously with the image *and* in the precise direction of motion, thus minimizing blur.

In wide-FOV astronomy, the problem of image motion is more complicated because the image motion is not uniform over the entire FOV but is decorrelated over angular distances of a few arc minutes. As a result, the motion compensation applied to a star at one side of the image would not be accurate for a star at the far side of the image. Thus, for wide-FOV imaging, an OTCCD would not be appreciably more effective than a traditional CCD.

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The OTCCD was developed in the mid-1990s by researchers at Lincoln Laboratory and the MIT campus. The motivation for this device was the desire to mitigate the image blur experienced in ground-based astronomical imaging. Small prototype devices were built at Lincoln Laboratory and tested by MIT astronomers at an observatory on Kitt Peak in Arizona. The results demonstrated both improved image sharpness and higher sensitivity over the relatively narrow FOV of the image sensor.

The solution for wide-FOV imaging

To solve these wide-FOV problems for Pan-STARRS, Lincoln Laboratory built an 8 × 8 array of OTCCDs on a single silicon chip. This architecture, the OTA, enabled each OTCCD to shift independently to track the varied image motion across a wide field and to correct for wavefront distortions. Data from the 64 OTCCDs builds the composite wide-area image.

Through a series of iterations on an OTA measuring 5 cm (~ 2 inches) per side, Laboratory researchers worked out the design and fabrication issues of the device.

Lincoln Laboratory then delivered 60 OTAs that the University of Hawaii assembled into a focal-plane array measuring about 16 inches on a side and containing 1355 megapixels, the largest, by a factor of four, such array in the world.

This large focal plane was installed in the prototype Pan-STARRS telescope and has been used in regular science observations beginning in 2009. The prototype optical system and three additional ones will compose the full Pan-STARRS, which will be used to detect Earth-approaching asteroids and comets that could be dangerous to the planet.

When the system becomes fully operational, the entire sky visible from Hawaii (about three-quarters of the total sky) will be photographed at least once a week. Pan-STARRS will also be used to catalog 99% of stars in the northern hemisphere that have ever been observed by visible light, including stars from nearby galaxies, providing astronomers with a resource for the study of small, distant, cool, and low-luminosity stars. ■

Additional Reading

B.E. Burke, J.A. Gregory, M. Cooper, et al., "CCD Imager Development for Astronomy," *Lincoln Laboratory Journal,* vol 16, no. 2, pp. 393–412, 2007.

J.L. Tonry, B.E. Burke, S. Isani, P.M. Onaka, and M.J. Cooper, "Results from the Pan-STARRS Orthogonal Transfer Array (OTA)," *Proceedings of SPIE,* vol. 7021, pp. 702105-1–702105-9, 2008.

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