Image Sensors: More Sensitivity Increases Options

New full-frame CCDs eliminate some trade-offs in performance and price.

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Many scientific, medical and industrial imaging applications rely on camera systems that contain high-performance charge-coupled device (CCD) sensors. These applications require sensors that provide high signal levels and very low noise. This capability allows users to acquire images more quickly or identify features that would otherwise not be clearly discernible.

For example, amateur astronomers use very long exposures with filters, especially in the blue, to achieve the correct balance for a full-color image (Figure 1). Increasing a detector's blue sensitivity means that astronomers can reduce blue exposure times, an important factor in minimizing motion effects that can degrade the quality of an image. Alternatively, they can maintain their acquisition time and use the detector's extra sensitivity to identify fainter astronomical objects.

Biologists, chemists, and other scientists and industrial users deal with similar trade-offs in terms of image acquisition time vs. the ability to identify faint signals. All can benefit from recent advances in high-sensitivity image sensor technology.

Image sensor trade-offs

People who need to acquire high-resolution images have several options for detectors:

• Full-frame CCDs are photosensitive over 100 percent of their sur-

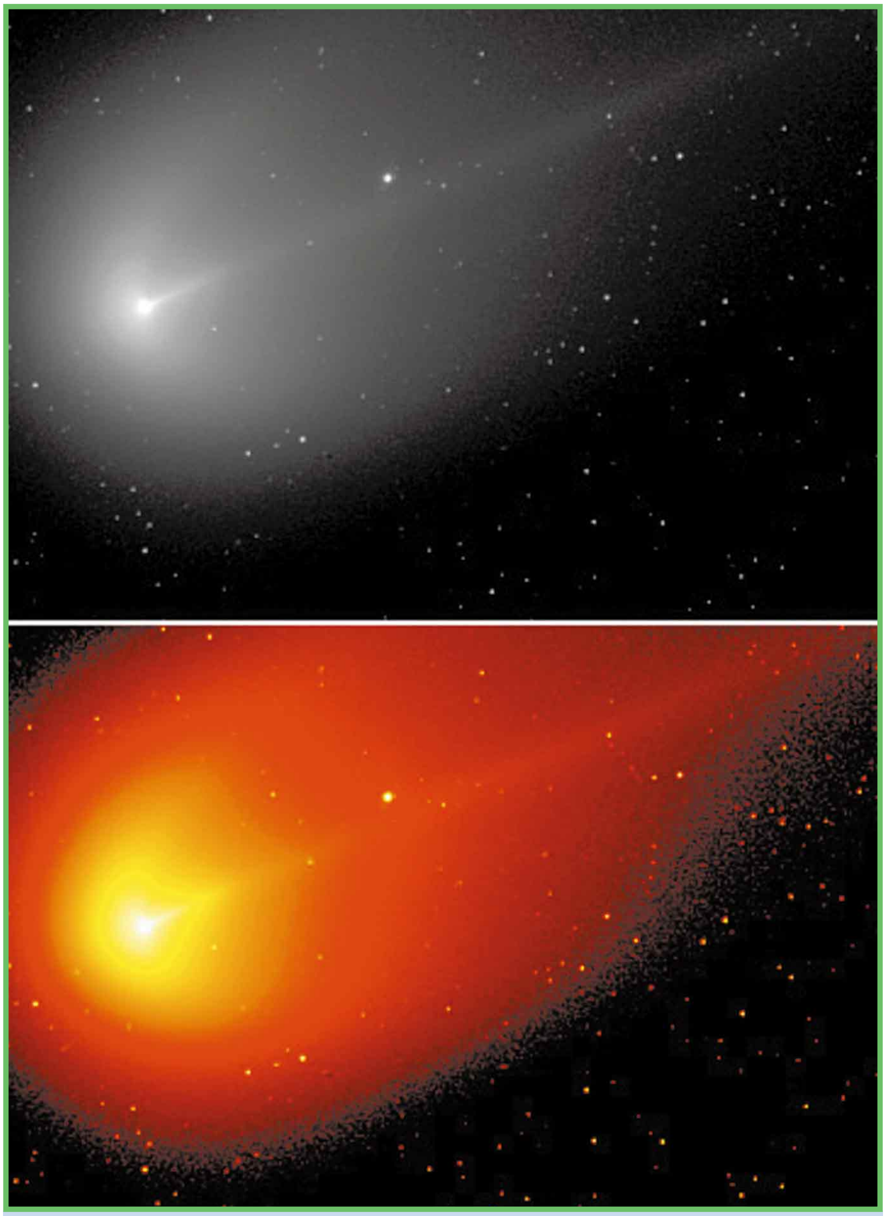

Figure 1. Amateur astronomy is among the scientific and industrial applications that could benefit from detectors that are more sensitive in the visible region of the spectrum. This would simplify the acquisition of a full-color image, such as this one of the Hyacolo comet. Courtesy of Michael Barber, Santa Barbara Instrument Group in Santa Barbara, Calif.

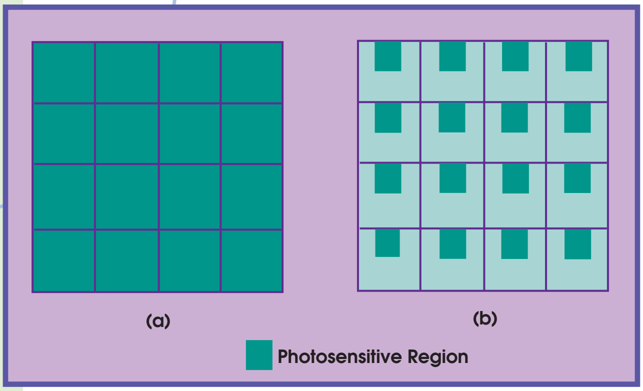

Figure 2. With full-frame detectors (a), 100 percent of the pixel area is photosensitive; with an interline-transfer detector (b), only part of the pixel is photosensitive. The balance of each pixel is devoted to charge storage and readout circuitry.

face area, so an electrode covers the entire area to read out the signal charge (Figure 2a). Cameras that use full-frame CCDs also include a mechanical shutter or strobe light to control the exposure. When the shutter is open or the strobe light on, charge accumulates in all pixels. When the shutter is closed or the strobe light off, the charge is read out. The architecture accommodates long exposure times, such as in astronomy, or very rapid acquisition times, such as for motion analysis or data collection in physical or biological science.

The drawback to this technology is that because 100 percent of the surface area is photosensitive, the electrode must cover each pixel if it is to read out the charge. Typically, the electrode material has been composed of polysilicon, which is only semitransparent in the visible portion of the spectrum. It absorbs and reflects some wavelengths there, thus reducing the sensor's overall quantum efficiency.

• Interline-transfer CCDs include an electronic shutter mechanism to control the exposure time. This means that each pixel contains a photosensitive area and a charge-transfer and readout area (Figure 2b). No electrode covers the photosensitive area, so quantum efficiency does not suffer. The trade-off for these devices is that only a fraction of the pixel area (as little as one-fifth) is photosensitive. This may be acceptable for applications that do not require wide dynamic range, but it is a problem for applications that need very long or very short exposure times.

• Back-illuminated CCDs are full-frame image sensors, polished from the back to remove most of the bulk silicon substrate. Light is imaged on this back side, but the polysilicon electrode is on the front, so it does not affect quantum efficiency. The trade-offs for these devices are cost and noise; they are expensive and require cooling to liquid-nitrogen temperatures to mitigate excess noise. Despite these disadvantages, they are still the best alternative for those applications that demand extremely high performance at any cost.

For users who need a less expensive but highly sensitive sensor, a new full-frame CCD provides an alternative. Blue Plus image sensors developed by Eastman Kodak Co. of Rochester, N.Y., use a new, transparent gate electrode material and fabrication process to improve their quantum efficiency (see "Electrode Improves CCD Sensitivity," *Photonics Spectra*, January 1999, p. 33). This results in much higher signals in the blue and green portions of the spectrum, boosting overall responsivity with no increase in sensor noise.

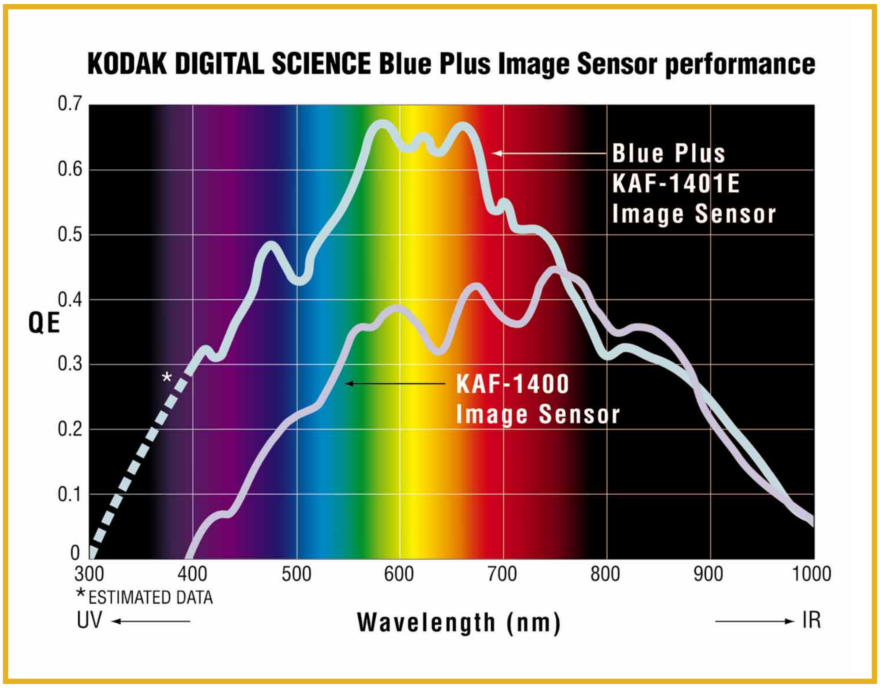

Figure 3. A proprietary transparent gate electrode improves quantum efficiency of the full-frame image sensor, compared with a standard polysilicon gate electrode.

While quantum efficiency above about 800 nm remains the same, visible spectrum response improves (Figure 3). For example, at 400 nm, the quantum efficiency improves from 2 to 30 percent. From 550 to 700 nm, it increases from 40 to 65 percent. In fact, the

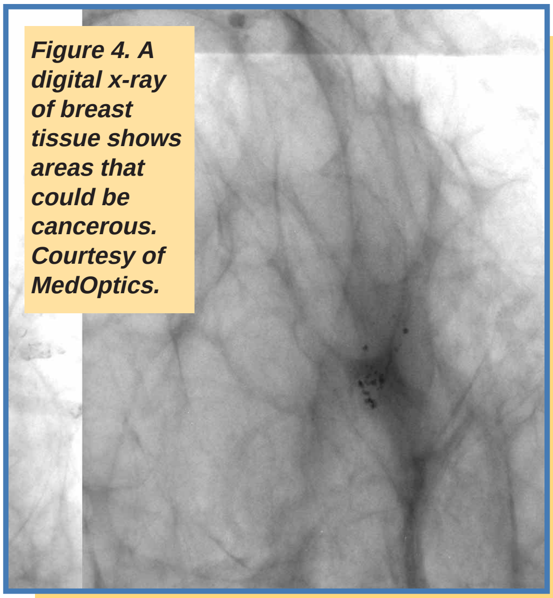

Figure 4. A digital x-ray of breast tissue shows areas that could be cancerous. Courtesy of MedOptics.

Digital x-ray imaging equipment is often used in breast biopsy procedures. In this application, physicians acquire two images of the breast and use stereotaxic triangulation to guide a needle to a suspicious site so that they can remove a tissue sample. MedOptics in Tucson, Ariz., provides equipment for this type of application. CCD-based x-ray imagers generally provide a 2 × 2-in. field of view (Figure 4), but physicians would like a wider field of view, said Emre Toker, MedOptics' president. Toker said the new Blue Plus sensor's responsivity should enable him to produce imagers that offer a 4 × 4-in. field of view without affecting image quality or acquisition time.

Similar improvements should be possible in industrial x-ray imaging applications, such as inspection to detect cracks in connectors or bond wires.

In the biological sciences, fluorescent dyes are often used to monitor changes in cells or for DNA sequencing. The dyes are made to bind selectively to certain sites on a cell under specific circumstances. The dyes are energized with UV light and fluoresce, usually in the green (Figure 5). Hugh Garvey, sensor specialist at Roper Scientific in Trenton, N.J., said scientists face a dilemma: UV lamps that excite the dyes can damage the cells over time, but the amount of dye at any location is usually very small, so the fluorescence can be very weak. Ideally, an experiment would use the shortest possible exposure, but then it would need a camera that is sensitive enough to detect very faint fluorescence signals.

Garvey said that Roper has verified the performance levels of Kodak's Blue Plus image sensors and is ready to use them in a full-frame camera line for this type of application. "We think acquisition times for some biological science processes can be significantly reduced," he added. □

spectral response surpasses that of an interline-transfer CCD. In addition, the technology opens up the spectral region from 300 to 400 nm, where standard full-frame image sensors have very low quantum efficiency.

One application that would immediately benefit from the technology is UV-VIS spectroscopy, which was previously possible only with back-illuminated CCDs. The astronomy application outlined in the opening paragraphs is another example.

Scientific and industrial users

X-ray imaging also can benefit from the technology. In digital x-ray imaging, a scintillator plate absorbs the x-rays, then re-emits green light corresponding to the x-ray intensity. A fiber optic taper transfers this light to the CCD sensor, which reads it out for real-time capture and viewing. The higher the sensor's responsivity, the shorter the x-ray exposure needed to acquire an image of a given quality. Alternatively, maintaining the exposure period may improve detection of the weakest x-ray signals, such as those returning from very small masses in mammography.

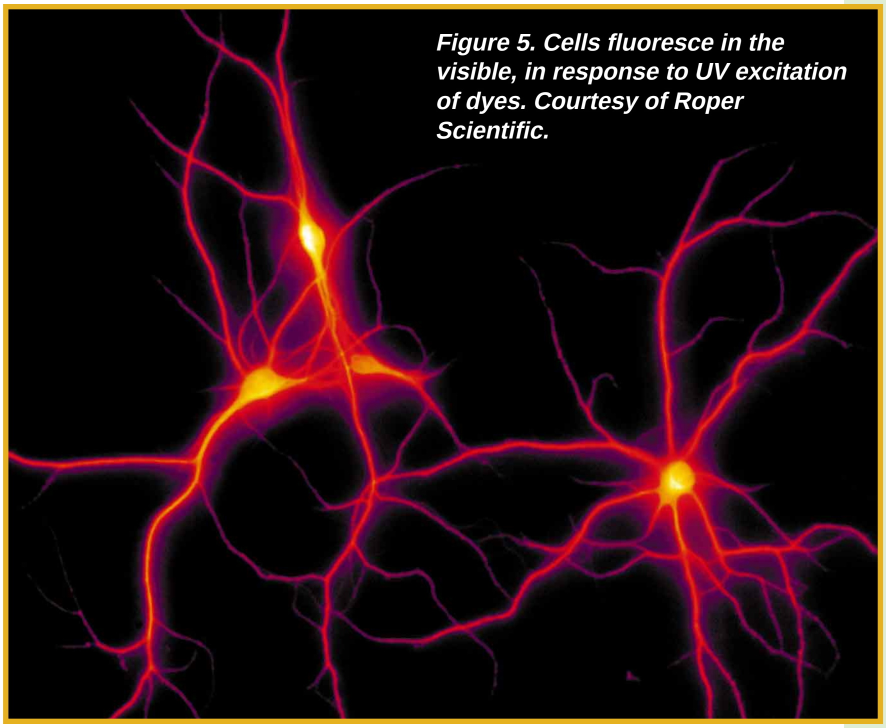

Figure 5. Cells fluoresce in the visible, in response to UV excitation of dyes. Courtesy of Roper Scientific.

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