R15: A Low-Light to Sunlight, 60 Frames/s, 80 kpixel CMOS APS Camera-on-a-Chip with 8b Digital Output

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Abstract:

In the last several years, many CMOS APS photodiode image sensors have been developed for consumer and commercial use. These sensors typically rely on illumination levels on the order of 100 Lux (a well-lit room) for optimal operation at video frame rates. While these sensors produce high-quality images under these conditions, there is significant image degradation as the light level is reduced, due to a combination of small pixel size, small pixel conversion gain and high read noise (greater than 25 e^-, resulting from the non-CDS nature of photodiode operation).

There are, of course, several applications that require much higher sensitivity than the CMOS APS photodiode can typically offer. Automotive applications, security cameras, and camcorders, among others, would all benefit from APS sensors which could provide high quality images at video rates in night or darkened indoor lighting conditions. In addition, the necessary optics could be simplified by the ability to operate the sensor over a continuous range of lighting up to full sunlit conditions with a fixed iris setting. These goals, however, are opposed to each other, necessitating a pixel with adjustable sensitivity. CCD sensors also have problems operating at both of these extremes, with the typically small pixel size limiting the low-light sensitivity and image smear interfering with bright light operation.

We report the development of a 342 by 258 element CMOS APS camera-on-a-chip capable of operation at 60 frames/s over the entire illumination range from < 0.02 Lux to bright sunlight (> 20,000 Lux). This sensor uses the photogate pixel with anti-blooming/shuttering capability developed by Fossum et.al.[1] and recently reported by Yang et.al.[2] The signal is processed using a column-parallel analog signal processor (ASP) with adjustable gain. The pixel has been measured to have an intrinsic conversion gain of 33 $\mu V/e^-$. The input-referred read noise is measured to be $5e^-$, equal to that reported by Yadid-Pecht et.al. in 1997[3], but now at 60 frames/s, or 4.8 Mpixel/s. In addition to the standard rolling and frame shutter modes of operation, a new, shuttered photodiode mode, which enables bright sunlight operation by reducing the pixel sensitivity by a factor of over 24, will be discussed. By varying the pixel sensitivity, on-chip gain, and integration time, the output sensitivity can be continuously adjusted from 9.3 V/lux (560 V/lux-s) to less than 50 μV/lux.

At this time, a fully flexible open architecture (FFOA) sensor has been fabricated and tested. Shown in Figure 1 are three images taken using this sensor, with identical frame times and iris settings (F= 1:1.4). The first image was captured with an ambient light level of 0.2 Lux. The second image was taken in bright room-lighting conditions (200 Lux). The final image was taken on a bright sunny day, with an illumination of over 20,000-Lux.

A camera-on-a-chip version of this sensor is currently being fabricated. This chip includes all timing-and-control functions, auto-exposure/gain control, and an 8-bit analog-to-digital converter. The performance of this chip will be reported at the conference.

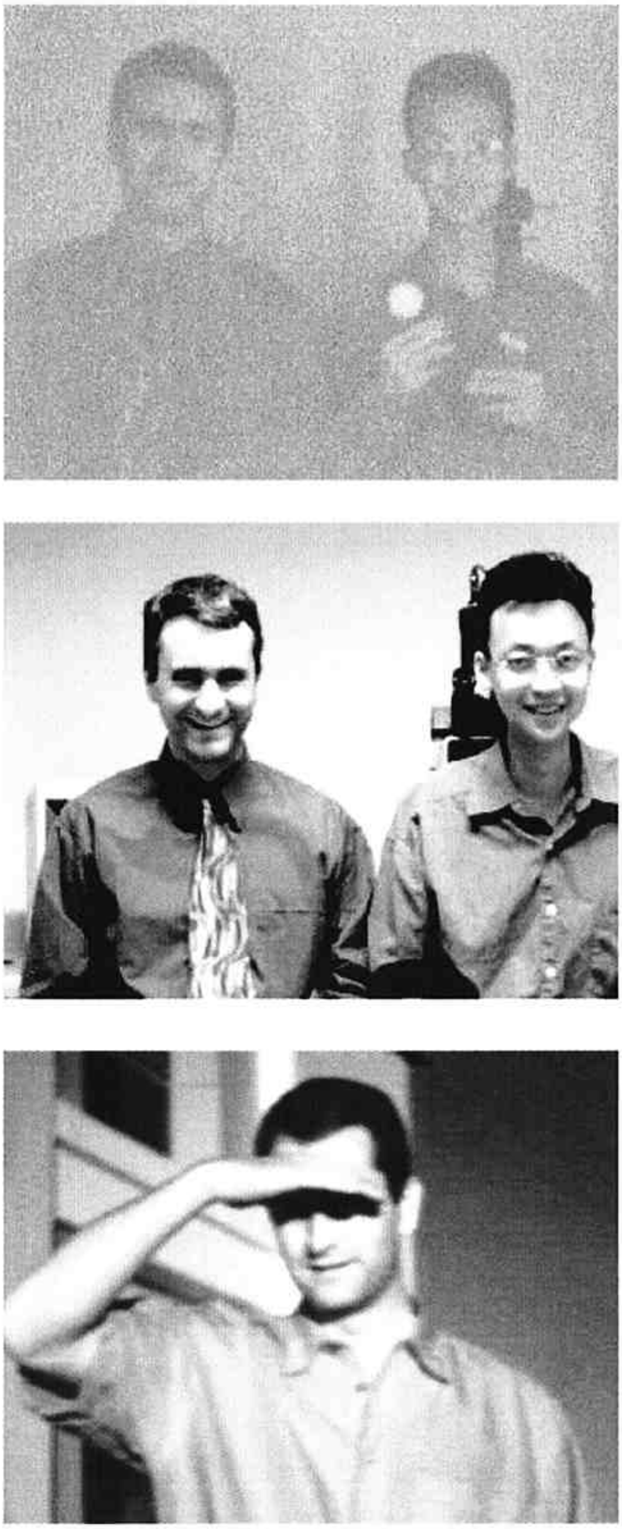

Figure 1: These three images were captured using the FFOA high sensitivity sensor at identical frame rates (60 fps) and iris settings (F= 1:1.4). The scene illumination in the top image was 0.2 Lux. The center image illumination was 200 Lux and the final illumination was greater than 20,000 Lux (bright sunlight).

References

1. Fossum, Eric, Sabrina Kemeny and Robert Nixon, "Active Pixel Sensor Array with Electronic Shuttering", U.S. Patent Application CIT Case #2247-2B, Jet Propulsion Laboratory, California Institute of Technology.

2. Yang, Guang, Orly Yadid-Pecht, Chris Wrigley, and Bedabrata Pain, "A Snap-Shot CMOS Active Pixel Imager for Low-Noise, High-Speed Imaging", *IEEE, International Electron Devices Meeting, 1998 Technical Digest*, Session 2, Paper 7.

3. Yadid-Pecht, Orly, Barmak Mansoorian, Eric R. Fossum, and Bedabrata Pain, "Optimization of Noise and Responsivity in CMOS Active Pixel Sensors for Detection of Ultra Low Light Levels"