11.9 An Active Range Finder With the Capability of -18dB SBR, 48dB Dynamic Range and 120 x 110 Pixel Resolution

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Some applications of 3-D measurements using a triangulation-based light projection method, such as a recognition system on vehicles, require operation with non-uniform background illumination and safe light levels for human eyes. Most imagers [1, 2] need a strong projected light when a target object is placed in a non-ideal environment such as strong background illumination. Correlation techniques provide one solution to the problem. The conventional correlation sensor [3], however, has a problem of signal saturation limiting its dynamic range. The range finder with an electronic shutter [4] decreases the SNR due to an extremely short shutter interval. It is difficult to adjust an optimal shutter interval autonomously, especially in non-uniform background rendering them inapplicable for wide variety of applications as mentioned above.

The basic idea [5] of the projected light detection sensing scheme, shown in Fig. 11.9.1a, achieves both high sensitivity and wide dynamic range in non-uniform background illumination. In addition, selective light detection is realized for a multiple-light-projection system as implemented in the circuit of Fig. 11.9.1b. The operation of the system uses a modulated projected light source with detection based on the modulating frequency. A constant illumination current-mode suppression circuit provides adaptive removal of background illumination and avoids saturation difficulties. A logarithmic response circuit limits the level of the ac component of the output current. A correlation circuit multiplies the alternating signal by a global external signal of a correlation frequency f0. Light can be detected by f0 when multiple lights of various modulation frequencies are projected on the scene. Integration of the correlation permits detection of extremely weak modulation signals. In addition, the pixel-parallel sensing scheme achieves quick detection for high-speed range finding.

Figure 11.9.2 shows a timing diagram of the sensing scheme. When the incident light is modulated the two components of photo current I_{pd} are a constant current I_{dc} due to background illumination and an alternating current I_{ac} due to modulated light. The average current I_{avg} generated by a low-pass filter is subtracted from the original photo current in the current-mode suppression circuit. The output current I_{mod} is converted to the voltage V_{mod} and correlated by the external signals, MPY+ and MPY-, synchronized with the correlation frequency. The integrator output voltages are now read. When the incident light is only background illumination, the photo current is constant, I_{mod} is zero and the difference voltage between V_{out+} and V_{out-} is zero. Alternatively, the difference voltage is acquired only when the incident light contains the correlation frequency. The pixel is activated when the difference voltage exceeds the reference voltage V_{cmp}.

The range finder of Fig. 11.9.3 is designed and fabricated in 0.6μm 2P 3M CMOS process. It is a 120 x 110 pixel array with column-parallel subtraction circuits and comparators. The pixel area is 60μm x 60μm with 13.5% fill factor.

Figure 11.9.4 shows the relationship between the background intensity E_{bg} and the minimum detectable intensity E_{proj_min} of the projected light. To evaluate the sensitivity of the light detection, the intensities of the projected light and the background illumination are measured by the photo current generated by each. The illuminance corresponding to the background photo current is shown in Fig. 11.9.4 (in the upper axis) for reference. The experimental results of the present sensor are shown by (a) in Fig. 11.9.4. The minimum signal-to-background ratio (SBR), indicating the sensitivity of the light detection, is -22.8dB. SBR is defined as 10 $\log(E_{proj\_min}/E_{bg})$. In addition, the high-sensitivity light detection under -18dB SBR is realized in dynamic range of over 48dB in terms of background illumination. It means that the present range finder is more applicable to wide variety of applications than the conventional correlation sensor with a saturation problem as shown by (b) in Fig. 11.9.4.

The correlation technique suppresses incident light of frequencies other than f_0 with a suppression ratio of less than -7dB. Even harmonics of f_0 have suppression ratios less than -13dB. Thus the projected lights of even-harmonics frequencies can be ideally separated. Such a separation of concurrently projected lights is important for triangulation-based range finding to reduce a dead angle, occuring when multiple lights from different directions illuminate a target object. Under these conditions light detection is realized up to 2000frames/s at -16dB SBR.

Figure 11.9.5 shows a measurement of weak light detection in strong and non-uniform background illumination. The modulated laser beam corresponding to 4 klx is projected on a target object. The maximum background intensity is 80 klx. The range finder detects the position of the projected laser beam clearly as shown in Fig. 11.9.5b. Its light detection has a tolerance to not only non-uniform background illumination but also target colors. The range finder is applied to 3-D measurement system and the range maps of Fig. 11.9.6a,b,c are acquired. The brightness of the range map means the distance from the range finder. The wire frame of the target object can be reproduced from the range data as shown in Fig. 11.9.6e. The maximum error of measured range in the effective area is 1.5mm at a distance of 1000mm. The characteristics of the sensor and its range finding system are summarized in Fig. 11.9.7.

Acknowledgements
The VLSI chip was fabricated by the VLSI Design and Education Center, Univ. of Tokyo, in collaboration with Rohm Co. and Toppan Printing Co.

References
[1] S. Yoshimura et al., "A 48k frame/s CMOS Image Sensor for Real-time 3-D Sensing and Motion Detection," *ISSCC Dig. of Tech. Papers*, pp. 94 – 95, 2001.
[2] V. Brajovic et al., "100 frames/s CMOS Range Image Sensor," *ISSCC Dig. of Tech. Papers*, pp. 256 – 257, 2001.
[3] A. Kimachi et al., "Time-Domain Correlation Image Sensor: First CMOS Realization and Eva luation," *IEEE Transducers '99*, pp. 958 – 961, 1999.
[4] R. Jeremias et al., "A CMOS Photosensor Array for 3D Imaging Using Pulsed Laser," *ISSCC Dig. of Tech. Papers*, pp. 252 – 253, 2001.
[5] Y. Oike et al., "High Performance Photo Detector for Modulated Lighting," *Proc. of IEEE Sensors 2002*, pp.1456 – 1461, 2002.

 0-7803-7707-9/03/$17.00

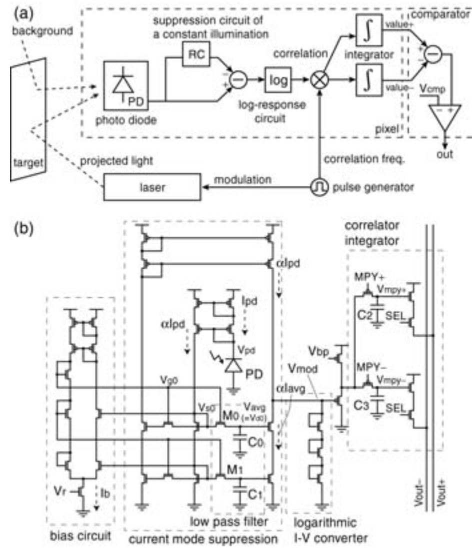

Figure 11.9.1: Sensing scheme – (a) basic idea; (b) circuit implementation.

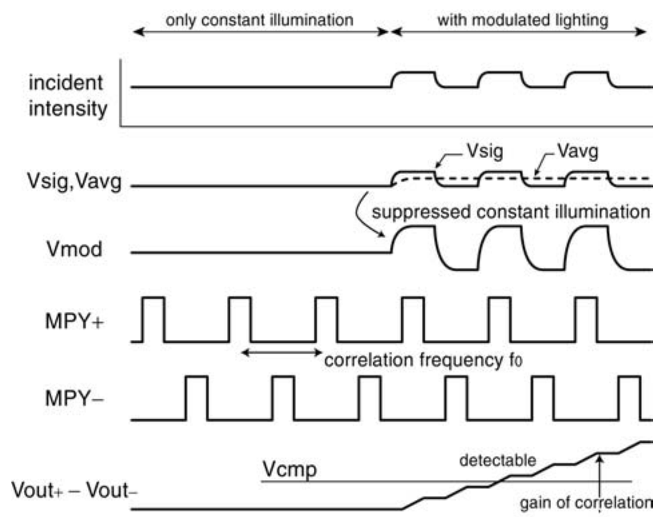

Figure 11.9.2: Pixel timing diagram.

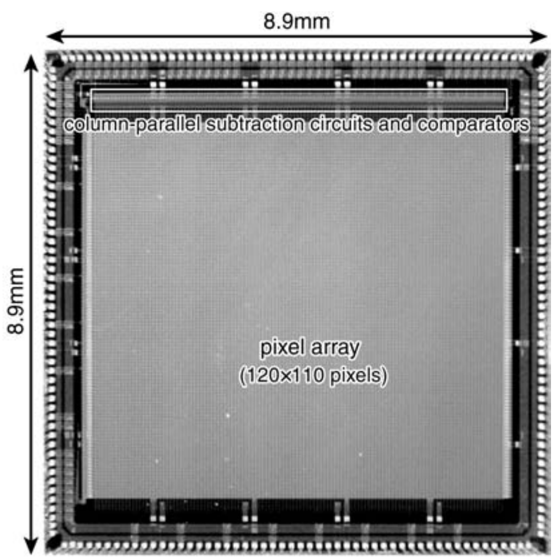

Figure 11.9.3: Die microphotograph.

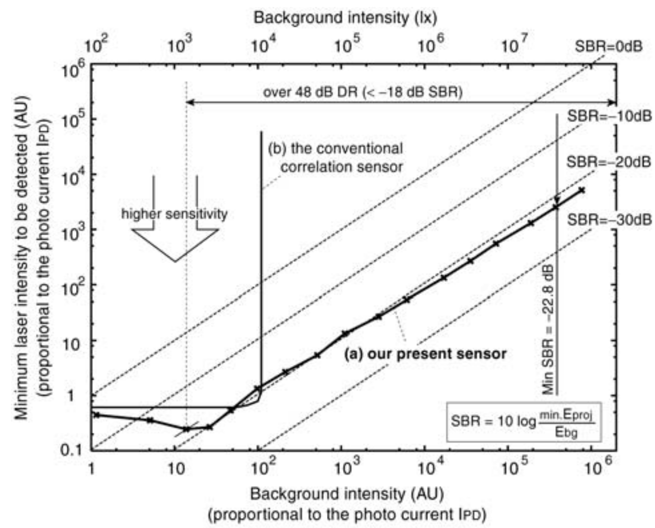

Figure 11.9.4: Sensitivity and dynamic range.

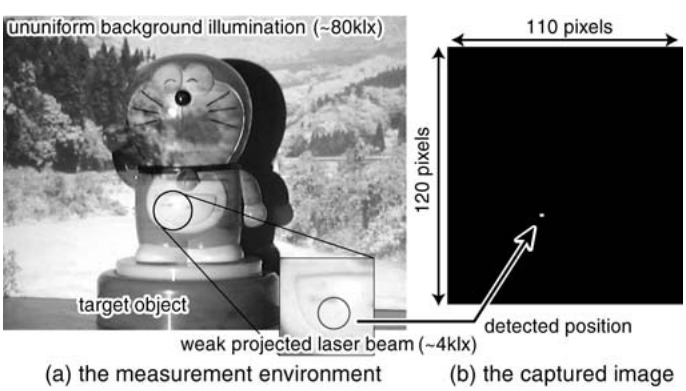

Figure 11.9.5: High sensitive position detection in non-uniform background illumination.

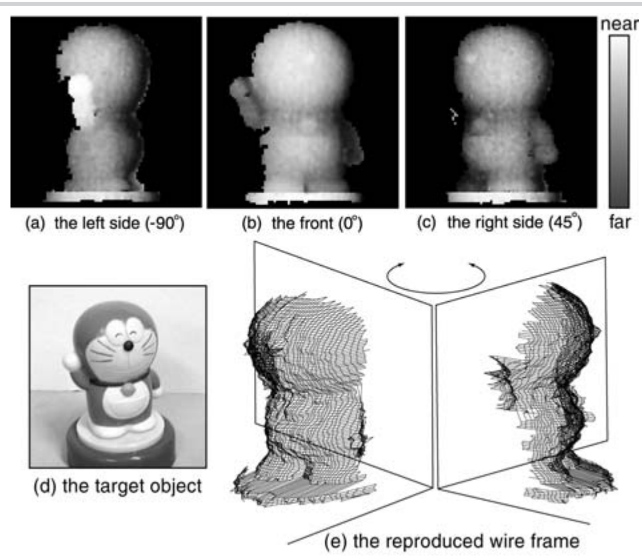

Figure 11.9.6: Measurement results of range finding.

Process	0.6 μm CMOS (2P, 3M)
Chip size	8.9 mm x 8.9 mm
Array size	120 x 110 pixels
Pixel size	60.0 μm x 60.0 μm
Fill factor	13.5 %
Power supply	5.0 V
Sensitivity (SBR)	-22.8 dB SBR
Dynamic range	> 48 dB (< -18 dB SBR)
Selectivity	-13 dB suppression ratio (for even harmonics of f_0)
Light detection rate	2000 fps (at -16 dB SBR)
Depth resolution	1.5 mm at 1000 mm
Power dissipation	250 mW

Figure 11.9.7: Sensor and system performance.

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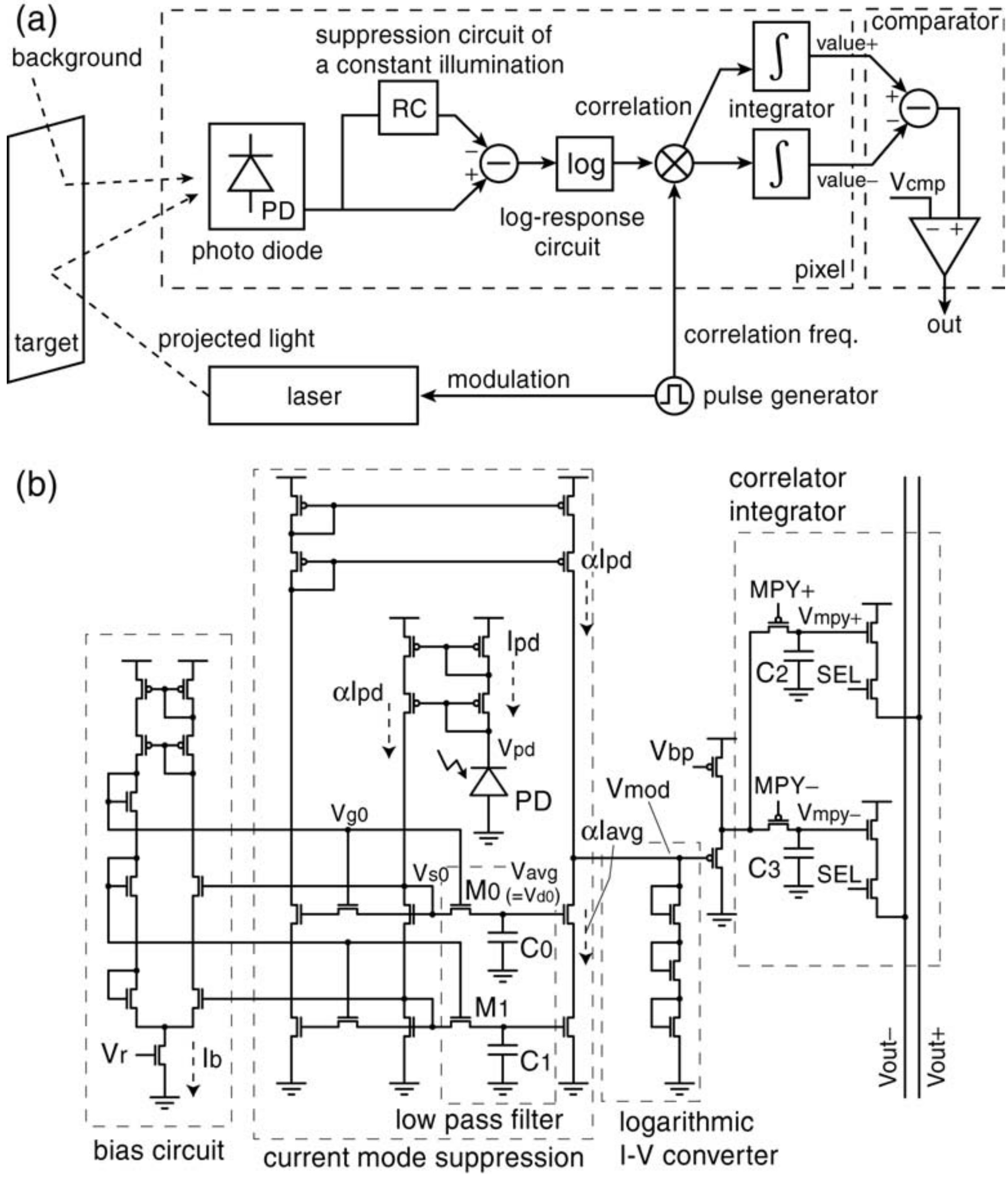

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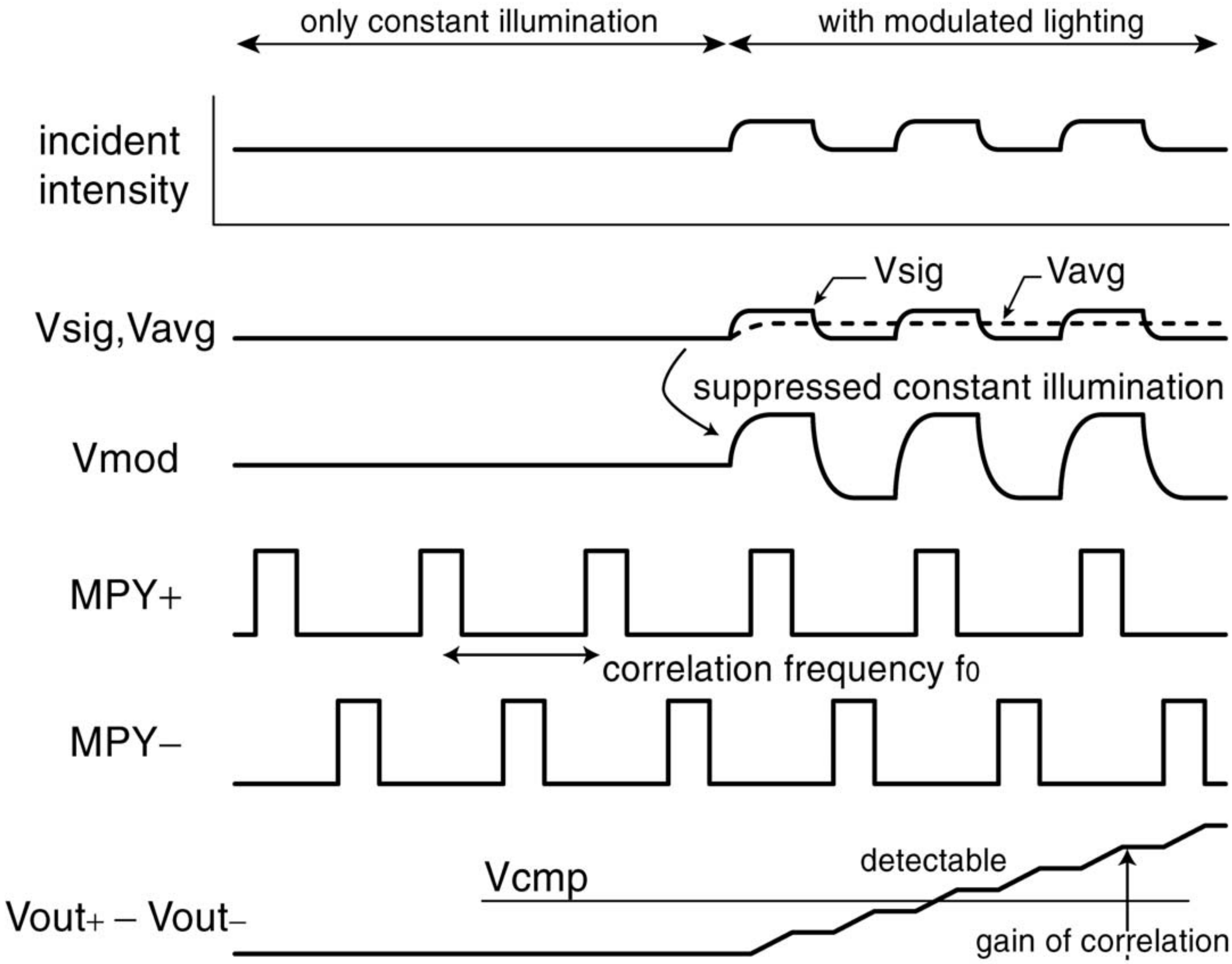

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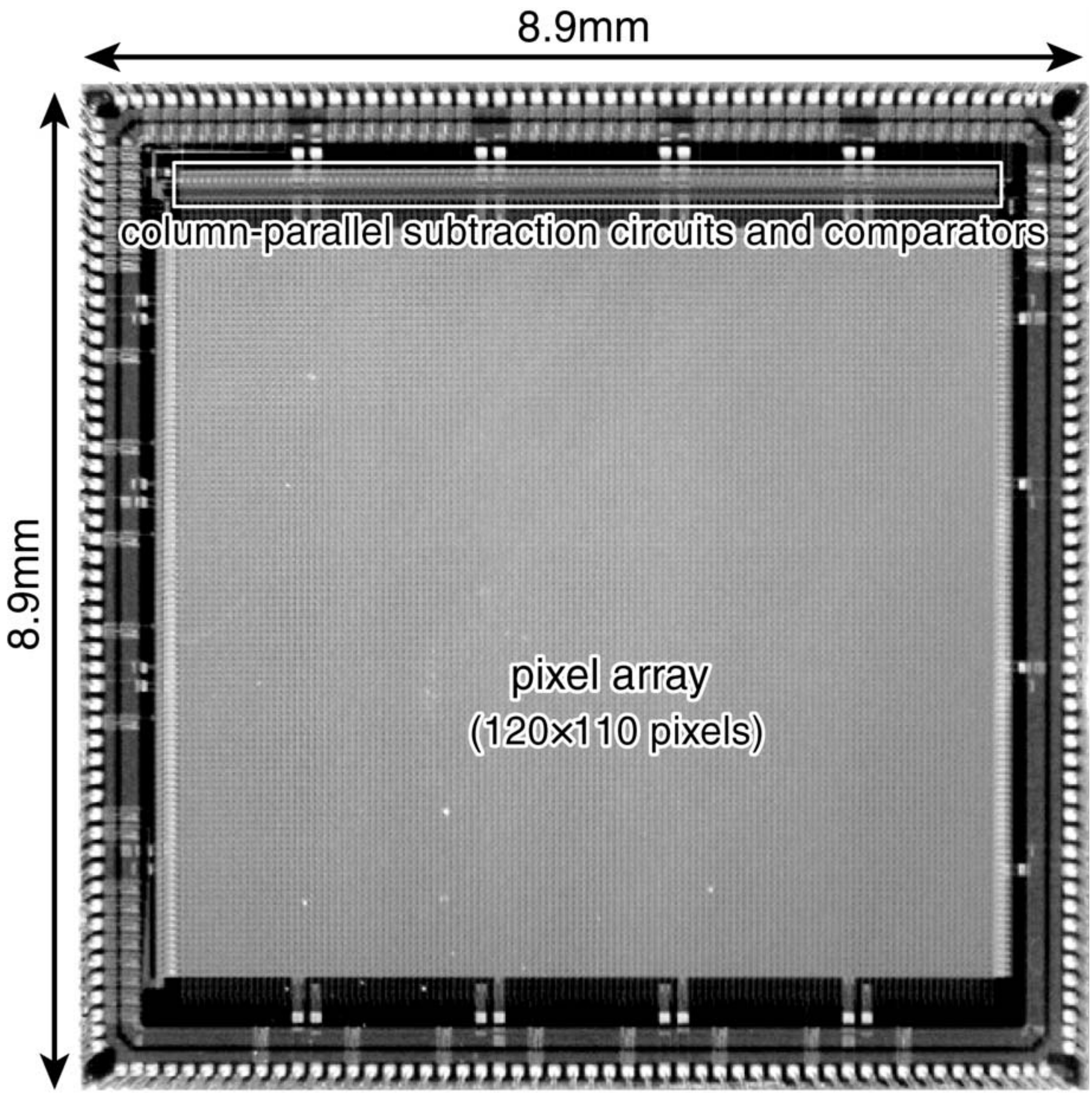

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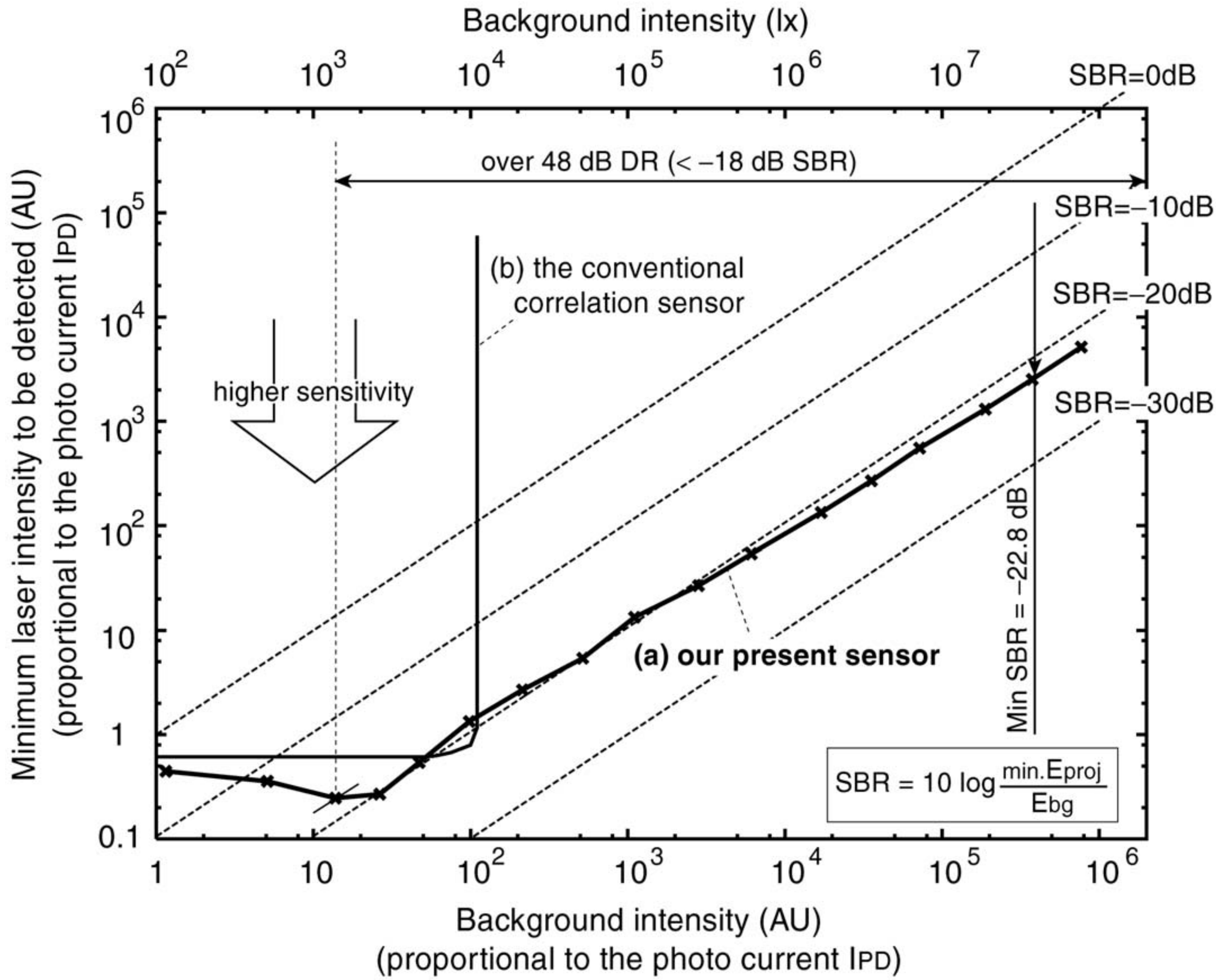

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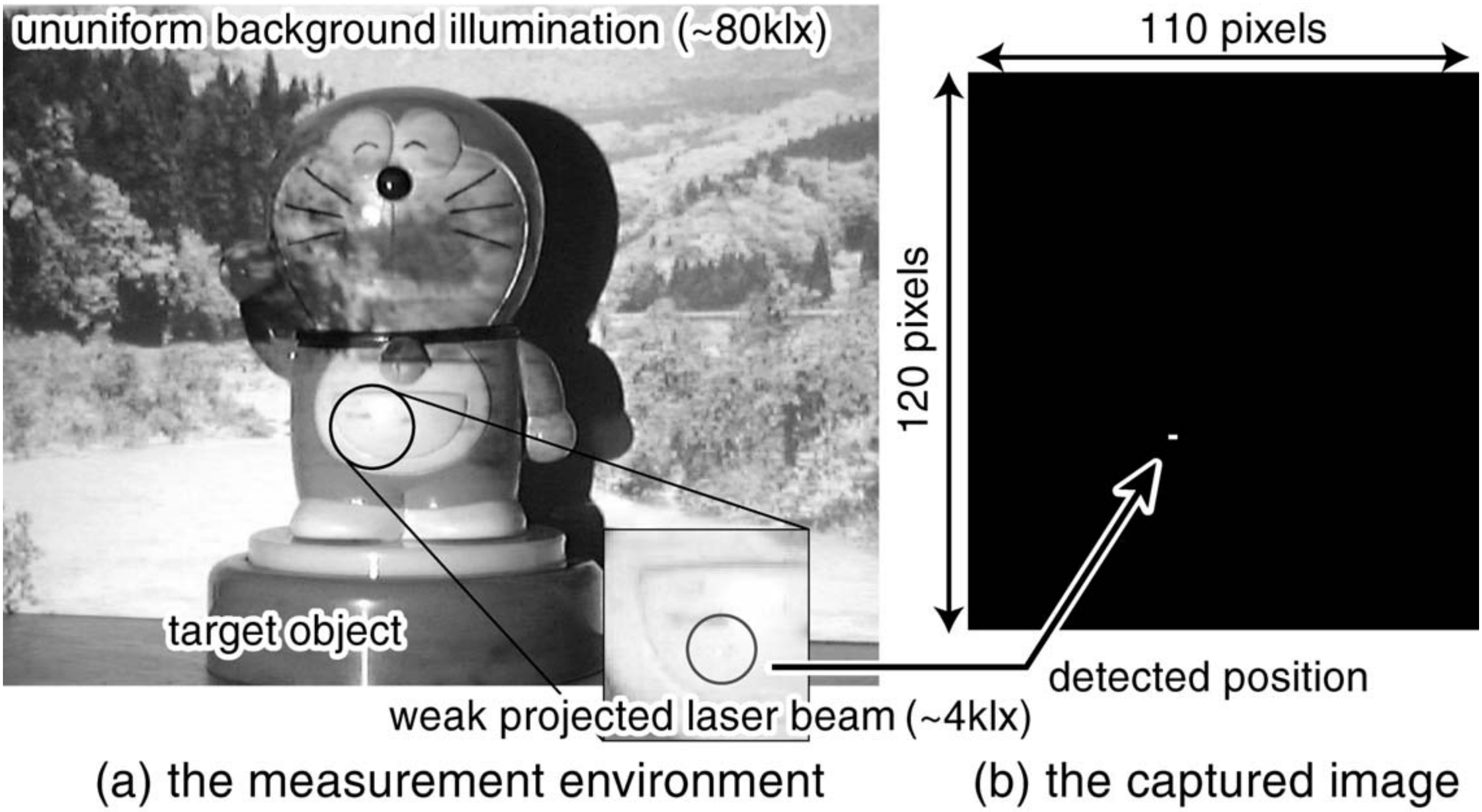
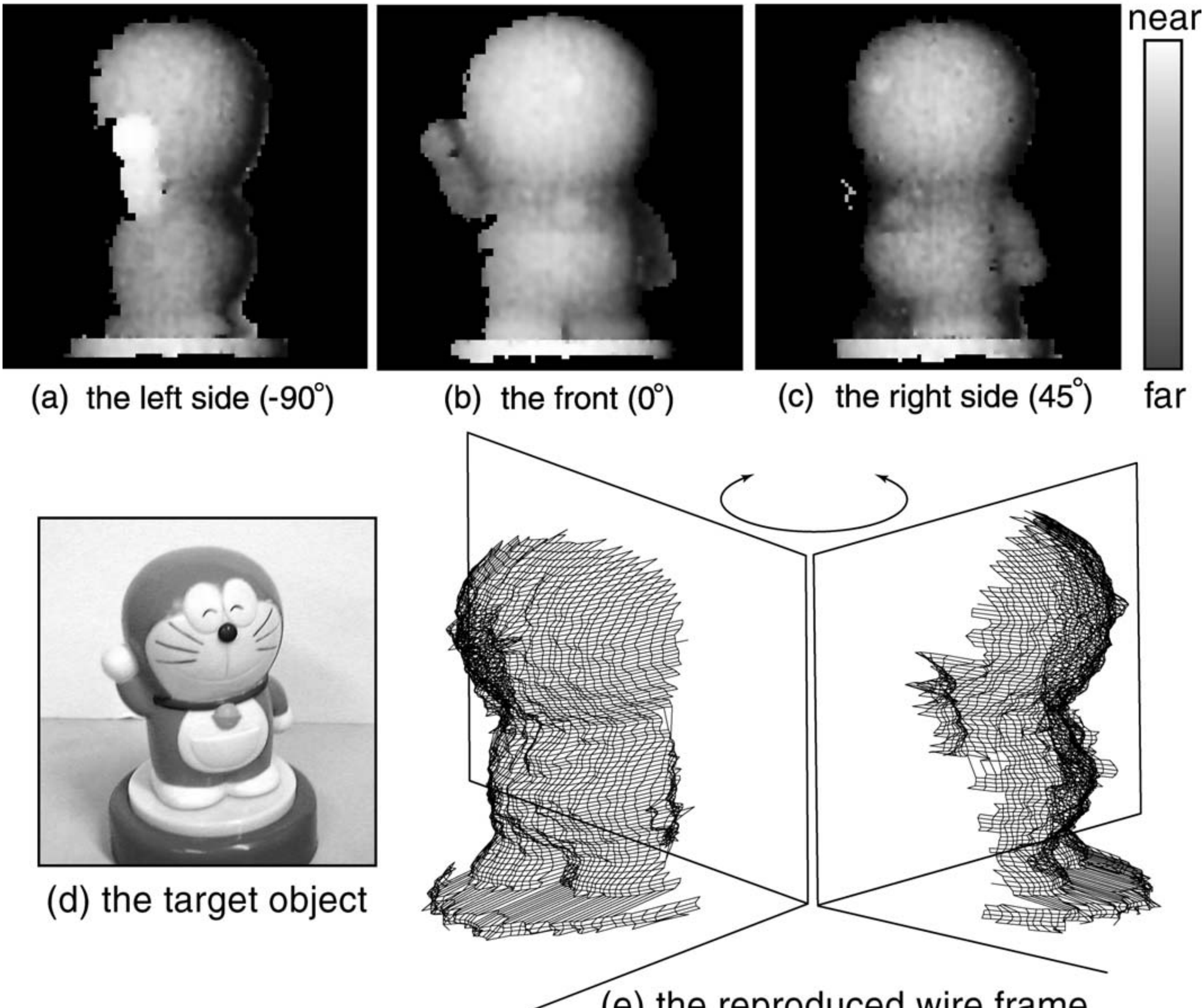


Figure 11.9.5: High sensitive position detection in non-uniform background illumination.



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