

# Bibliography

## Pixel designs and HDR pixels

1. M. Waeny, S. Lauxtermann, N. Blanc, M. Willemin, M. Rechsteiner, E. Doering, J. Grupp, P. Seitz, F. Pellandini, and M. Ansorge, “High-sensitivity, high-dynamic, digital CMOS imager: Paper B,” *Proc. SPIE* **4306**, 78 (2001) [doi:10.1117/12.426992].
2. B. Fowler, “High dynamic range image sensor architectures,” Stanford Univ. WDR Workshop (Sep. 2009).
3. T. Lulé, B. Schneider, M. Bohm, et al, “Design and fabrication of a high dynamic range image sensor in TFA technology,” *IEEE J. Solid State Cir.* **34**(5), 704–711 (1999).
4. W. Yang, “A wide dynamic range low power photosensor array,” *Proc. IEEE ISSCC* **37**, 230–231 (1994).
5. O. Vietze, “Active pixel image sensors with application specific performance based on standard silicon CMOS processes,” PhD Thesis, No. 12038, ETH Zurich, Switzerland, (1997).
6. D. X. D. Yang, A. El Gamal, B. Fowler, and H. Tian, “A  $640 \times 512$  CMOS image sensor with ultrawide dynamic range floating-point pixel-level ADC,” *IEEE J. Solid State Circ.* **34**(12), 1821–1834 (1999).
7. T. F. Knight Jr., “Design of an integrated optical sensor with on-chip preprocessing,” PhD Thesis, MIT, Boston, MA (June 1983).
8. M. Barbaro, P.-Y. Burgi, A. Mortara, P. Nussbaum, and F. Heitger, “A  $100 \times 100$  pixel silicon retina for gradient extraction with steering filter capabilities and temporal output coding,” *IEEE J. Solid State Circ.* **37**(2), 160–172 (2002).
9. O. Yadid-Pecht, “Wide-dynamic-range sensors,” *Opt. Eng.* **38**(10), 1650–1660 (1999).
10. B. Dierickx, N. Witvrouwen, and B. Dupont, “DC and AC high dynamic range pixels,” Image Sensor Conf., London (March 2008).
11. J. Huppertz, R. Hauschild, B.J. Hosticka, T. Kneip, S. Miler, and M. Schwarz, “Fast CMOS imaging with high dynamic range,” Proc. Workshop CCD and Advanced Image Sensors, R7-1–R7-4, Bruges, Belgium (June 1997).

12. M. Schanz, C. Nitta, A. Bumann, B. J. Hosticka, and R. K. Wertheimer, “A high dynamic range CMOS image sensor for automotive applications,” *IEEE J. Solid State Circ.* **35**(7), 932–938 (2000).
13. M. Schanz, W. Brickhende, R. Hauschild, B. J. Hoticka, and M. Schwarz, “Smart CMOS image sensor arrays,” *IEEE Trans. Electron Dev.* **44**, 1699–1705 (1997).
14. O. Yadid-Pecht and A. Belenky, “In-pixel autoexposure CMOS APS,” *IEEE J. Solid State Circ.* **38**(8), 1425–1428 (2003).
15. O. Yadid-Pecht and E. Fossum, “Wide intrascene dynamic range CMOS APS using digital sampling,” *IEEE Trans. Electron Dev.* **44**, 1721–1723 (1997).
16. B. Fowler, D. Yang, A. El Gamal, and H. Tian, “A CMOS image sensor with ultrawide dynamic range floating-point pixel-level ADC,” *IEEE J. Solid State Circ.* **34**, 1821–1834 (1999).
17. K. Brehmer, S. J. Decker, R. D. McGrath, and C. G. Sodini, “A CMOS imaging array with wide dynamic range pixels and column-parallel digital output,” *IEEE J Solid State Circ.* **33**, 2081–2091 (1998).
18. R. Hauschild, M. Hillebrand, B. J. Hosticka, J. Huppertz, T. Kneip, and M. Schwarz, “A CMOS image sensor with local brightness adaptation and high intrascene dynamic range,” *Proc. ESSCIRC*, 308–311 (1998).
19. E. Funatsu, Y. Nitta, Y. Miyake, T. Toyoda, K. Hara, H. Yagi, J. Ohta, and K. Kyuma, “Artificial retina chip with a  $256 \times 256$  array of n-mos variable sensitivity photodetector cells,” *Proc. SPIE* **2597**, 283–291 (1995) [doi:10.1117/12.223990].
20. J. Trumblin, A. Agrawal, and R. Raskar, “Why I want a gradient camera,” *Proc. IEEE CVPR* (2005), see <http://www.umiacs.umd.edu/~aagrawal/1323GradCamFinal.pdf> (last accessed July 2012).
21. V. Branzoi, S. K. Nayar, and T. Boult, “Programmable imaging using a digital micromirror array,” *Proc. IEEE CVPR*, 436–443 (2004).
22. S. K. Nayar and T. Mitsunaga, “High dynamic range imaging: spatially varying pixel exposures,” *Proc. IEEE CVPR*, 472–479 (2000).
23. E. Fossum, “CMOS active pixel image sensor,” *Nucl. Instrum. Methods A* **395**, 291–297 (1995).
24. E. Fossum, “Image capture circuits in CMOS,” *VLSI Tech. Syst. Appl.*, 52–57 (1997).
25. S. Kavusi and A. El Gamal, “Quantitative study of high dynamic range image sensor architectures,” *Proc. SPIE* **5301**, 264 (2004) [doi:10.1117/12.544517].
26. A. Uehara, K. Kagawa, T. Tokuda, J. Ohta, and M. Nunoshita, “A high-sensitive digital photosensor using MOS interface-trap charge pumping,” *IECE* **1**(18), 556–561 (2004).
27. L. G. McIlrath, “A low-power low-noise ultrawide-dynamic-range CMOS imager with pixel-parallel A/D conversion,” *IEEE J. Solid State Circ.* **36**(5), 15 (2001).

28. A. El Gamal, "High dynamic range image sensors," *Proc. IEEE ISSCC* (2002).
29. B. Dierickx, D. Scheffer, G. Meynants, W. Ogiers, and J. Vlummens, "Random addressable active pixel image sensors," *Proc. SPIE* **2950**, 1 (1996) [doi:10.1117/12.262512].
30. G. Meynants, B. Dierickx, D. Scheffer, and A. Krymsky, "Sensor for optical flow measurements based on differencing in space and time," *Proc. SPIE* **2645**, 108 (1996) [doi:10.1117/12.236090].
31. D. Scheffer, B. Dierickx, and F. Pardo, "Design and fabrication of a CMOS log-polar image sensor," *Proc. SPIE* **2784**, 2 (1996) [doi:10.1117/12.248520].
32. N. Ricquier and B. Dierickx, "Active-pixel CMOS image sensor with on-chip non-uniformity correction, Proc. IEEE Workshop on CCD and Advanced Image Sensors, 20–21 (1995).
33. N. Ricquier, I. Debusschere, B. Dierickx, A. Alaerts, J. Vlummens, and C. Claeys, "The CIVIS sensor: a flexible smart imager with programmable resolution," *Proc. SPIE* **2172**, 2 (1994) [doi:10.1117/12.172755].
34. N. Ricquier and B. Dierickx, "Smart image sensors for robotics and automation," 3rd ESA ASTRA Workshop, Estec, Noordwijk, NL (17–18 April 1994).
35. N. Ricquier and B. Dierickx, "Pixel structure with logarithmic response for intelligent and flexible imager architectures," *Microelectron. Eng.* **19**, 631 (1992).
36. D. Yang and A. El Gamal, "Comparative analysis of SNR for image sensors with enhanced dynamic range," *Proc. SPIE* **3649**, 197 (1999) [doi:10.1117/12.347075].
37. Y. Ni, Y. Zu, and B. Arian, "A  $768 \times 576$  logarithmic image sensor with photodiode in solar cell mode," New Imaging Technologies SA, Verrières le Buisson, France, see <http://www.new-imaging-technologies.com/media/doc/isw2011.pdf> (last accessed July 2012).
38. Y. Ni and K. Matou, "A CMOS log image sensor with on-chip FPN compensation," see <http://www.imec.be/esscirc/esscirc2001/Proceedings/data/24.pdf> (last accessed July 2012).

### **Software HDR methods, tone-mapping algorithms, and perception**

39. F. Durand and J. Dorsey, "Fast bilateral filtering for the display of high dynamic range images," *Proc. ACM SIGGRAPH*, 257–265 (2002).
40. E. Reinhard, M. Stark, P. Shirley, and J. Ferwada, "Photographic tone reproduction for digital images," *Proc. ACM SIGGRAPH* **21**(3) (2002).

41. S. Mann and R. Picard, “Being ‘undigital’ with digital cameras: extending dynamic range by combining different exposure times,” *Proc IST*, 422–428 (1995).
42. S. Winder, S. B. Kang, M. Uyttendaele, and R. Szeliski, “High dynamic range video,” *Proc ACM SIGGRAPH* **22**(3), 319–325 (2003).
43. S. K. Nayar and V. Branzoi, “Adaptive dynamic range imaging: optical control of pixel exposures over space and time,” *Proc. IEEE* **2**, 1168–1175 (2003).
44. M. D. Grossberg and S. K. Nayar, “Determining the camera exposure from images: what is knowable?,” *IEEE Trans. Patt. Anal. Mach. Intell.* **35**(11), 1455–1467 (2003).
45. Y. Y. Schechner and S. K. Nayar, “Generalized mosaicing: high dynamic range in a wide field of view,” *Int. J. Comput. Vision* **53**(3), 245–267 (2003).
46. M. Aggarwal and N. Ahuja, “High dynamic range panoramic imaging,” Proc. of International Conference on Computer Vision (ICCV), 2–9 (2001).
47. R. Mantiuk and H.-P. Seidel, “Modeling a generic tone mapping operator,” *Eurographics* **27**(2) (2008).
48. E. Reinhard and K. Devlin, “Dynamic range reduction inspired by photoreceptor physiology,” *IEEE Trans. Visual. Comput. Graphics* **11**, 15–24 (2011).
49. R. Mantiuk, “High dynamic range imaging: towards the limits of the human visual perception,” *Forschung und wissenschaftliches Rechnen* **72**, 11–27 (2006).
50. See <http://www.openexr.com> (last accessed July 2012).
51. See <http://www.unifiedcolor.com> (last accessed July 2012).
52. G. Ward, “High Dynamic Range Image Encodings,” see [http://www.anyhere.com/gward/hdrenc/hdr\\_encodings.html](http://www.anyhere.com/gward/hdrenc/hdr_encodings.html) (last accessed July 2012).
53. E. Reinhard, E. Arif Khan, A. Oguz Akyüz, and G. M. Johnson, *Color Imaging Fundamentals and Applications*, AK Peters Ltd, Boca Raton, FL (2008).
54. A. O. Akyüz and E. Reinhard, “Noise reduction in high dynamic range imaging,” *J. Vis. Commun. Image R.* **18**(5), 366–376 (2007).
55. J. J. McCann, “Art science and appearance in HDR images,” *J. Soc. Info. Display* **15**(9), 709–719 (2007).
56. J. J. McCann and A. Rizzi, “Camera and visual veiling glare in HDR images,” *J. Soc. Info. Display*, **15**(9), 721–730 (2007).
57. P. E. Debevec and J. Malik, “Recovering high dynamic range radiance maps from photographs,” *Proc. ACM SIGGRAPH*, 369–378 (1997).
58. M. Ashikhmin, “A tone mapping algorithm for high-contrast images,” 13th Eurographics Workshop on Rendering, 1–11 (2002).

59. R. Fattal, D. Lischinski, and M. Werman, "Gradient domain high dynamic range compression," *Proc. ACM SIGGRAPH*, 249–256 (2002).
60. R. Mantiuk, K. Myszkowski, and H. P. Seidel, "A perceptual framework for contrast processing of high dynamic range images," *ACM TAP* 3(3) (2006).
61. S. Pattanaik and H. Yee, "Adaptive gain control for high dynamic range image display," *Proc. SCCG*, 24–27 (2002).

### Measurement and characterization methods

62. European Machine Vision Association 1288 Standardization Group, "EMVA1288 standard 2010 release 3," see <http://www.standard1288.org> (last accessed July 2012).
63. F. Dierks, *Comparing Cameras using EMVA1288*, Basler AG, Ahrensburg, Germany (2006).
64. D. X. D. Yang and A. El Gamal, "Comparative analysis of SNR for image sensors with enhanced dynamic range," *Proc. SPIE* 3649, 197 (1999) [doi:10.1117/12.347075].
65. S. O. Otim, D. Joseph, B. Choubey, and S. Collins, "Modelling of high dynamic range logarithmic CMOS image sensors," *Proc. IEEE Instrum. Measure.* 1, 451–456 (2004).
66. J. R. Janesick, *Photon Transfer*, SPIE Press, Bellingham, WA (2007) [doi:10.1117/3.725073].
67. D. Hertel, "Extended use of incremental signal-to-noise ratio as reliability criterion for multiple-slope wide dynamic range image capture," *J. Electron. Imag.* 19, 011007 (2010) [doi:10.1117/1.3267100].
68. D. Wueller and U. Artmann, "Test methods for digital still cameras," *Test Methods for Digital Still Cameras*, Image Engineering, Frechen, Germany, see <http://www.imageengineering.com/> (last accessed July 2012).

### General HDR

69. A. Darmont, "Methods to extend the dynamic range of snapshot active pixels sensors," *Proc. SPIE* 6816, 681603 (2008) [doi:10.1117/12.761600].
70. A. Wilson, "Dynamic design," *Vision Syst. Design* 14(10), 35–39 (2009).

### General image sensors

71. A. Darmont, "Spectral response of CMOS image sensors," Aphesa, Harze, Belgium (2009).
72. G. C. Holst and T. S. Lomheim, *CMOS/CCD Sensors and Camera Systems*, Second Edition, JCD Publishing, Winter Park, FL (2011).

- 73. H. Tian and A. El Gamal, "Analysis of 1/f noise in CMOS APS," *Proc. SPIE* **3965**, 168 (2000) [doi:10.1117/12.385433].
- 74. M. T. Rahman, N. Kehtanaravaz, and Q. R. Razlighi, "Using image entropy maximum for auto exposure," *J. Electron. Imag.* **20**(1), 013007 (2011) [doi:10.1117/1.3534855].
- 75. J. C. Dunlap, W. C. Porter, E. Bodegom, and R. Widenhorn, "Dark current in an active pixel complementary metal-oxide-semiconductor sensor," *J. Electron. Imag.* **20**(1), 013005 (2011) [doi:10.1117/1.3533328].

### **Photography and optics**

- 76. L. Johnes and H. Condit, "The brightness scale of exterior scenes and the computation of correct photographic exposures," *J. Opt. Soc. Am.* **31**, 651–678 (1941).

### **Miscellaneous**

- 77. S. Maddalena, A. Darmont, and R. Diels, "Automotive CMOS image sensors," 9<sup>th</sup> International Forum on Advanced Microsystems for Automotive Applications (AMAA), 401–412 (2005).
- 78. A. Darmont, "CMOS imagers: from consumer to automotive," MST News (June 2004).
- 79. W. Karwowski, *International Encyclopedia on Ergonomics and Human Factors, Second Edition*, Vol. 1, 1484, CRC Press, Boca Raton, FL (2006).
- 80. S. Masumura, "Carry out the mission of light, basic and application of lighting technology in machine vision system," Series on Lighting Technology, Eizojojo Industrial, Sangyo Kaihatsukiko Inc., Tokyo, Japan (April 2004).
- 81. K. Devlin, "A review of tone reproduction techniques," Tech. Report CSTR-02-005, Dept. Computer. Science, Univ. of Bristol, UK (2002).
- 82. L. Straniero, see <http://www.flickr.com/photos/24630856@N08> (last accessed July 2012).
- 83. B. Dierickx, "Course on CMOS image sensors," Caeleste (2009), see [http://www.caeleste.be/publicaties\\_bart/publicatielijst.htm](http://www.caeleste.be/publicaties_bart/publicatielijst.htm) (last accessed July 2012).
- 84. C. Lofqvist, see page <http://www.flickr.com/photos/43052603@N00> (last accessed July 2012).
- 85. R. Xu, et al., "High dynamic range image and video data compression," *IEEE Computer Graphics and Applications*, **25**(6), 69–76 (2005).
- 86. B. Jähne, *Digitale Bildverarbeitung*, Springer, Berlin (2005).

# Index

1/f noise, 34, 104

3T pixel, 57–59, 73–76, 81

4T pixel, 59, 60, 99

## A

absolute radiance map, 122

airbag, 3

artifact, 33, 57, 58, 60, 70, 94, 135

## B

barcode, 6

Bayer pattern, 114

beam splitter, 105

## C

color channel, 114, 115, 126

color correction matrix, 155

color space, 114, 153–155

computer graphics, 120

correlated double sampling (CDS),  
32–34

current-gain-amplifier, 104, 105

## D

dark current, 36, 37, 59, 62

dark signal non-uniformity  
(DSNU), 30, 31

Debevec, Paul, 7, 123, 129

demosaicing, 114

depth of focus, 121

dynamic range, 1, 6–8, 11, 16,  
18, 21, 23, 38–49, 54, 62, 63,  
87, 94, 100

dynamic range enhancement factor  
(DRF), 85, 87

dynamic range gaps, 46, 47, 52

dynamic well adjustment, 82

## E

EMVA1288 standard, 30, 35, 39,  
123, 160, 161

Enz–Krummenacher–Vittoz (EKV)  
equation, 96

exposure value (EV), 92

## F

fixed pattern noise (FPN), 33, 95

flare, 141, 142

flicker noise, 34

flickering, 148

full-well capacity, 100

## G

gamma, 14, 32

gamut, 133, 154, 157

ghosting, 131, 141

ghosts, 131

glare, 141, 143, 144

global operators, 135

global shutter, 34, 61, 100

## H

halo, 8, 135, 137

histogram, 12, 17, 18, 37, 52, 53

human vision system, 53, 54,  
135

**I**

image information, 49, 52  
 image lag, 29, 99, 100  
 independent areas of integration (IAOI), 107  
 integration time, 70, 71, 107  
 International Organization for Standardization (ISO), 18, 43, 123, 159–162  
 irradiance, 24, 38, 39, 44, 122, 123

**J**

Johnson noise, 34

**K**

kneepoint, 72, 83, 149  
 kTC noise, 33, 99

**L**

lane departure warning (LDW), 136  
 lateral overflow, 72, 82  
 LinLog™ sensor, 104  
 local operators, 106, 135  
 logarithmic compression with feedback, 104  
 logarithmic pixel, 96, 99

**M**

Malik, Jitendra, 123, 129  
 Mann, Steve, 7  
 metamerism, 53, 54, 115  
 misalignments, 131  
 multiple independent exposure window (MIEW), 107  
 multiple segments, 71, 82, 83  
 multiple slopes, 45, 65, 82  
 multiple-exposure window, 106, 107

**N**

neutral density filter, 121, 163

**O**

optical effects, 33

**P**

park assist, 2  
 pedestrian detection, 2, 5  
 photo response non-uniformity (PRNU), 30, 31, 38, 41  
 photoconversion layers, 104  
 photocurrent, 36, 62, 65, 68–70, 74, 75  
 photography, 6, 7, 18, 92, 121  
 photon flux, 62  
 photon shot noise, 24, 25, 36  
 photovoltaic, 99  
 Picard, Rosalind, 7, 129  
 piecewise linear response (PWLR), 45, 47, 65, 90, 91  
 pixel array, 30, 150, 151  
 pixel clamping, 71  
 pixel control, 56  
 pixel design, 56, 74, 81, 109, 116  
 pixel radiance, 122  
 Poisson distribution, 22  
 Poisson’s law, 22, 25  
 power supply rejection ratio (PSRR), 33, 35, 81  
 proportional-integral-derivative (PID) controller, 148

**Q**

quantization noise, 32, 35  
 quantum efficiency, 26–29

**R**

radiance, 122  
 radiance map, 7, 123, 126  
 readout circuit, 29, 30, 38, 78  
 reciprocity principle, 123  
 relative radiance map, 122, 156  
 reset noise, 33, 34, 84  
 road sign detection, 5  
 rolling shutter, 57, 59, 81, 139

**S**

S-curve, 32, 123

saturation, 39–43, 62, 65  
saturation capacity, 65  
scene radiance, 122  
security, 4  
shot-noise-adapted quantization, 113  
shutter, 56, 57, 116  
shutter time, 147  
silver halide film, 123  
skimming, 82  
SNR holes, 46, 150  
storage element, 56, 66–68

**T**

thermal noise, 34, 38

tone mapping, 8, 18, 121, 126,  
133–135  
traffic monitoring, 4  
traffic sign recognition, 2  
tunnel, 4, 106

**V**

vantage point, 121  
veiling glare, 43, 143, 144

**W**

Wäny, Martin, 57  
welding, 1  
well sizing, 82



**Arnaud Darmont** (1979–2018) held a degree in Electronic Engineering from the University of Liège (Belgium, EU) oriented towards imaging science; he worked for over fifteen years in the field of imaging, HDR imaging, camera design, machine vision, and camera characterization. He authored several publications and patents in the field of HDR imaging, automotive on-board imaging, image processing applications, and camera test and characterization.

After almost 7 years developing automotive HDR CMOS image sensors at Melexis, he founded Aphesa in 2008. Aphesa specialized in image sensor consulting, HDR imaging, custom camera design, custom image processing solutions, image sensor and camera characterization and benchmarking. Aphesa was one of the main contributors to the European Machine Vision Association (EMVA)1288 standard, and Darmont was a member of the EMVA1288 working group since almost the beginning of the standard. Aphesa merged with Deltatec in 2017, and Darmont served as business development manager and technical expert.

Since December 2017, he was also the manager of standards at the EMVA, has launched new standards, and coordinated the international development of industrial imaging standards. He was a contributor to the IEEE P2020 automotive image quality standard and the IEEE P4001 hyperspectral imaging standard.

He was an SPIE instructor since 2009 and provided image sensor and industrial imaging courses to companies since 2015.