
Contents

Acknowledgements	xiii
Chapter 1. First Contact	1
1.1. Toward a society of the image	1
1.1.1. A bit of vocabulary in the form of zoology	4
1.1.2. A brief history of photography	7
1.2. The reason for this book	10
1.3. Physical principle of image formation	11
1.3.1. Light	11
1.3.2. Electromagnetic radiation: wave and particle	12
1.3.3. The pinhole	13
1.3.4. From pinholes to photo cameras	15
1.4. Camera block diagram	21
Chapter 2. The Photographic Objective Lens	25
2.1. Focusing	26
2.1.1. From focusing to blurring	26
2.1.2. Focusing complex scenes	28
2.2. Depth of field	34
2.2.1. Long-distance photography	35
2.2.2. Macrophotography	36
2.2.3. Hyperfocal	37
2.3. Angle of view	38
2.3.1. Angle of view and human visual system	38
2.3.2. Angle of view and focal length	39
2.4. Centered systems	41
2.4.1. Of the importance of glasses in lenses	42

2.4.2. Chromatic corrections	45
2.4.3. The choice of an optical system	47
2.4.4. Diaphragms and apertures	50
2.4.5. Zoom	53
2.4.6. Zoom and magnification	54
2.5. Fisheye systems	57
2.5.1. Projection functions	57
2.5.2. Circular and diagonal fisheyes	59
2.5.3. Fisheyes in practice	61
2.6. Diffraction and incoherent light	63
2.6.1. Coherence: incoherence	63
2.6.2. Definitions and notations	65
2.6.3. For a single wavelength	66
2.6.4. Circular diaphragm	68
2.6.5. Discussion	70
2.6.6. Case of a wide spectrum	71
2.6.7. Separation power	73
2.7. Camera calibration	74
2.7.1. Some geometry of image formation	74
2.7.2. Multi-image calibration: bundle adjustment	77
2.7.3. Fisheye camera calibration	78
2.8. Aberrations	79
2.8.1. Chromatic aberration	79
2.8.2. Geometrical aberrations	80
2.8.3. Internal reflections	82
2.8.4. Vignetting	83
2.8.5. The correction of the aberrations	86
Chapter 3. The Digital Sensor	89
3.1. Sensor size	90
3.1.1. Sensor aspect ratio	90
3.1.2. Sensor dimensions	91
3.1.3. Pixel size	93
3.2. The photodetector	93
3.2.1. Image detection materials	93
3.2.2. CCDs	94
3.2.3. CMOSs	97
3.2.4. Back-side illuminated arrangement (BSI), stacked arrangement	101
3.2.5. Stacked arrangements	102
3.2.6. Influence of the choice of technology on noise	103

3.2.7. Conclusion	104
3.3. Integrated filters in the sensor	104
3.3.1. Microlenses	104
3.3.2. Anti-aliasing filters	106
3.3.3. Chromatic selection filters	109
Chapter 4. Radiometry and Photometry	111
4.1. Radiometry: physical parameters	112
4.1.1. Definitions	112
4.1.2. Radiating objects: emissivity and source temperature	116
4.1.3. Industrial lighting sources	122
4.1.4. Reflecting objects: reflectance and radiosity	123
4.2. Subjective aspects: photometry	125
4.2.1. Luminous efficiency curve	126
4.2.2. Photometric quantities	128
4.3. Real systems	128
4.3.1. Etendue	129
4.3.2. Camera photometry	130
4.4. Radiometry and photometry in practice	134
4.4.1. Measurement with a photometer	134
4.4.2. Integrated measurements	137
4.5. From the watt to the ISO	138
4.5.1. ISO sensitivity: definitions	138
4.5.2. Standard output ISO sensitivity SOS	143
4.5.3. Recommended exposure index	143
4.5.4. Exposure value	144
Chapter 5. Color	145
5.1. From electromagnetic radiation to perception	147
5.1.1. The color of objects	147
5.1.2. Color perception	149
5.2. Color spaces	151
5.2.1. The CIE 1931 RGB space	153
5.2.2. Other chromatic spaces	160
5.2.3. The Lab space	162
5.2.4. Other colorimetric spaces	163
5.2.5. TV spaces	164
5.2.6. The sRGB space	165
5.2.7. ICC profile	168
5.2.8. Chromatic thresholds	169

5.3. The white balance	170
5.3.1. Presettings	171
5.3.2. Color calibration	172
5.3.3. Gray test pattern usage	173
5.3.4. Automatic white balance techniques	173
5.3.5. The Retinex model	175
5.4. Acquiring color	178
5.4.1. “True color” images	181
5.4.2. Chromatic arrays	186
5.4.3. Chromatic selection of the arrays	192
5.5. Reconstructing color: demosaicing	195
5.5.1. Linear interpolation demosaicing	196
5.5.2. Per channel, nonlinear interpolations	199
5.5.3. Interchannel, non-linear interpolations	199
Chapter 6. Image Quality	205
6.1. Qualitative attributes	206
6.1.1. The signal–noise ratio	207
6.1.2. Resolution	211
6.1.3. The modulation transfer function	215
6.1.4. Sharpness	221
6.1.5. Acutance	221
6.2. Global image quality assessment	226
6.2.1. Reference-based evaluations	228
6.2.2. No-reference evaluation	230
6.2.3. Perception model evaluation	234
6.3. Information capacity	237
6.3.1. The number of degrees of freedom	238
6.3.2. Entropy	243
6.3.3. Information capacity in photography	245
6.4. What about aesthetics?	252
6.4.1. Birkhoff’s measure of beauty	253
6.4.2. Gestalt theory	254
6.4.3. Shannon information theory, Kolmogorov Complexity and Computational Complexity theory	254
6.4.4. Learning aesthetic by machine	254
Chapter 7. Noise in Digital Photography	257
7.1. Photon noise	258
7.1.1. Fluctuations in the optical signal	258
7.1.2. The Poisson hypothesis in practice	261

7.1.3. From photon flux to electrical charge	262
7.2. Electronic noise	265
7.2.1. Dark current	265
7.2.2. Pixel reading noise	266
7.2.3. Crosstalk noise	266
7.2.4. Reset noise	267
7.2.5. Quantization noise	267
7.3. Non-uniform noise	268
7.3.1. Non-uniformity in detectors	268
7.3.2. Salt-and-pepper noise	268
7.3.3. Image reconstruction and compression noise	268
7.4. Noise models for image acquisition	269
7.4.1. Orders of magnitude	270
Chapter 8. Image Representation: Coding and Formats	273
8.1. “Native” format and metadata	274
8.2. RAW (native) format	275
8.2.1. Contents of the RAW format	278
8.2.2. Advantages of the native format	280
8.2.3. Drawbacks of the native format	281
8.2.4. Standardization of native formats	281
8.3. Metadata	283
8.3.1. The XMP standard	283
8.3.2. The Exif metadata format	284
8.4. Lossless compression formats	286
8.4.1. General lossless coding algorithms	287
8.4.2. Lossless JPEG coding	288
8.5. Image formats for graphic design	289
8.5.1. The PNG format	289
8.5.2. The TIFF format	291
8.5.3. The GIF format	292
8.6. Lossy compression formats	292
8.6.1. JPEG	294
8.6.2. JPEG 2000	299
8.7. Tiled formats	304
8.8. Video coding	305
8.8.1. Video encoding and standardization	306
8.8.2. MPEG coding	307
8.9. Compressed sensing	310

Chapter 9. Elements of Camera Hardware	313
9.1. Image processors	313
9.1.1. Global architecture and functions	314
9.1.2. The central processing unit	315
9.1.3. The digital signal processor	318
9.1.4. The graphics processing unit	320
9.2. Memory	321
9.2.1. Volatile memory	321
9.2.2. Archival memory cards	321
9.3. Screens	327
9.3.1. Two screen types	327
9.3.2. Performance	329
9.3.3. Choice of technology	330
9.4. The shutter	333
9.4.1. Mechanical shutters	333
9.4.2. Electronic shutters	333
9.5. Measuring focus	335
9.5.1. Maximum contrast detection	337
9.5.2. Phase detection	340
9.5.3. Focusing on multiple targets	341
9.5.4. Telemeter configuration and geometry	342
9.5.5. Mechanics of the autofocus system	343
9.5.6. Autofocus in practice	344
9.6. Stabilization	346
9.6.1. Motion sensors	346
9.6.2. Compensating for movement	349
9.6.3. Video stabilization	352
9.7. Additions to the lens assembly: supplementary lenses and filters	353
9.7.1. Focal length adjustment	353
9.7.2. Infra-red filters	356
9.7.3. Attenuation filters	357
9.7.4. Polarizing filters	358
9.7.5. Chromatic filters	365
9.7.6. Colored filters	366
9.7.7. Special effect filters	367
9.8. Power cells	367
9.8.1. Batteries	368
9.8.2. Rechargeable Ni-Cd batteries	368
9.8.3. Lithium-ion batteries	369

Chapter 10. Photographic Software	373
10.1. Integrated software	374
10.1.1. Noise reduction	374
10.1.2. Classic approaches	375
10.1.3. Iterative methods	376
10.1.4. Non-local approaches	377
10.1.5. Facial detection	379
10.1.6. Motion tracking	382
10.1.7. Image rotation	384
10.1.8. Panoramas	385
10.2. Imported software	394
10.2.1. Improving existing functions	395
10.2.2. Creating new functions	395
10.3. External software	397
10.3.1. High-dynamic images (HDR)	397
10.3.2. Plenoptic imaging: improving the depth of field	402
10.3.3. Improving resolution: super-resolution	408
10.3.4. Flutter-shutters	412
Bibliography	417
Index	439