Index

3D reconstruction, 123
5+1-point algorithm, 274
5-point algorithm, 260
7-point algorithm, 255
8-point algorithm, 253

affine point, 43
affine transformation, 55
affine transformation group, 55
affine vector, 43
algebraic constraint, 181
algebraic distance, 38
algebraic error, 38, 180
algebraic representation, 147
algebraic representation of $SO(3)$, 149
algebraically independent, 117
aperture, 93, 282
associative operation, 332
automatic camera calibration, 280
auxiliary variables, 193, 218, 258, 293
axis-angle representation, 150

backward interpolation, 301
barrel distortion, 285
barycentric coordinates, 236
baseline, 123
blending, 302
block diagonal matrix, 340
block matrix, 339
bounding box, 108, 296
Brown-Conrady distortion, 287
bundle adjustment, 317, 318

C-normalized image coordinates, 98
calibrated epipolar geometry, 121, 252
calibration device, 290
camera, 93
camera calibration, 107, 212, 279
camera center, 92
camera centered coordinate systems, 94
camera matrices from **F**, 131
camera matrix, 92
camera normalized image coordinates, 98
camera obscura, 93
camera projection matrix, 92
camera resectioning, 106
canonical form, 28, 30, 63, 64, 68, 71
canonical homogeneous coordinates, 88
Cardano angles, 162
Cartesian representation, 18
Cayley transform, 156
central perspective, 91
central projection, 91
centroid, 175
Closed form concatenation of rotations, 150
Closed form inverse of a rotation, 150
co-linear planes, 22
co-linear points, 18, 22
co-planar lines, 22
co-planar points, 21
collineation, 83
column compression, 344
commutative operation, 332
complete representation, 149
consensus set, 265
consistent parameterization, 218
consistent Plücker coordinates of 3D line, 70
constraint enforcement, 219
    fundamental matrix, 253
    normalized camera matrix, 242
    rotation matrix, 233
corner points, 186
correspondence, 121
correspondence problem, 194, 195
corresponding points, 121, 191
cost function, 174
cross product, 335
cross product matrix, 335
cross product operator, 335
cross-correlation, 175

D-normalization, 32
data degeneracy, 197
data error, 187
data matrix, 34, 179
decentering distortion, 287
degeneracy
    epipolar geometry estimation, 255
    homography estimation, 197
degenerate configuration, 50
degenerate data, 33
degrees of freedom, 49, 217

depth, 97
depth-of-field, 282
descent direction, 360
direct linear transformation, 117, 193
directed line, 39
direction, 43
distibutive operation, 332
distortion center, 288
DL-normalization, 71
DLT, 193
double embedding of $SO(3)$, 159
dual homogeneous coordinates, 30, 65
dual line normalization, 32, 71
dual Plücker coordinates, 47, 69
dual transformation, 60
duality mapping, 70
duality principle, 47

Eckart-Young (-Mirsky) teorem, 347
ego-motion estimation, 318
energy function, 174
epipolar constraint, 117, 121, 127
epipolar geometry, 121
    degenerate, 255
epipolar homographies, 126
epipolar line, 124, 128
epipolar plane, 124
epipolar points, 123
epipoles, 123
equation of the line, 18
equation of the plane, 21
equilibrating transformation, 207
equivalent cameras, 113
error function, 174
essential matrix, 121, 139, 140
    estimation
        robust, 274
    internal constraint, 140
estimation
    camera matrix, 210
    epipolar geometry, 245
    fundamental matrix, 252
    homography, 191
    introduction, 173
    rigid transformation, 235
    rotations, 231
    transforamtions, 191
Euclidean reconstruction, 135
Euler angles, 162
exterior orientation, 104, 235
external camera parameters, 104

FET, 286
field of view, 118
field of view model, 286
fish-eye lens, 282
fish-eye transform, 286
focal length, 94
focal point, 92
forward interpolation, 301
FOV, 286
full rank pseudo-inverse, 337
fundamental matrix, 121, 127
    camera matrices from, 131
    estimation, 252
        robust, 273
    internal constraint, 127

Gauss-Newton method, 364
general configuration, 50
geometric distortion, 282
geometric objects, 27
gimbal lock, 169
gold standard method, 258

H-normalization, 207
hand-eye calibration, 235
Hartley normalization, 207
homogeneous coordinates, 25, 28, 63
homogeneous method, 183
homogeneous representation, 18
homography, 83
homography estimation
    degeneracy, 197
    robust, 272
homography transformation, 83
hybrid method, 364

ICP, 237
ideal data, 187
ideal point, 43
identical noise, 188
identity element, 332
identity rotation, 150
image coordinate system, 101
image coordinates, 92
image mosaic, 296
image mosaicking, 296
image plane, 92
image point, 92
incidence relations, 32
independent noise, 188
indeterministic estimation method, 265
inhomogeneous method, 181
inliers, 262
inner derivatives, 220
intercept, 20
interior orientation, 104
internal camera parameters, 104
internal constraint

essential matrix, 140
fundamental matrix, 127
normalized camera matrix, 99
Plücker coordinates, 70
rotation matrix, 148
Internal constraint of a representation, 150
invariances, 49
inverse Cayley transform, 157
inverse of a quaternion, 334
involution, 58
isotropic noise, 188
iterative closest point, 237

Jacobian, 363
Jacobian mask, 324, 368

keystone effect, 86

L-normalization, 68
L_1 error, 179
L_2 error, 179
left inverse, 338
left singular vectors, 341
lens distortion, 282
lens distortion function, 283
lens effect, 282
Levenberg-Marquardt method, 364
line at infinity, 44, 67
line normalization, 68
linear transformation, 331

matrix exponential function, 350
matrix logarithm, 351
maximum likelihood estimation, 188
mean, 175
measurement error, 187
measurement noise, 110
method degeneracies, 251
method degeneracy, 197
mid-point method, 246
minimal case estimation, 196
minimal parameterization, 104, 130
ML-estimation, 188
model error, 184
Moore-Penrose inverses, 338
motion stereo, 123

nearest neighbor interpolation, 111, 301
Newton's method, 362
non-linear optimization, 359
normalized 8-point algorithm, 254
normalized camera, 97
normalized camera matrix, 98, 99
internal constraint, 99
normalizing transformation, 204, 207

objective function, 174
observation, 187
omni-directional camera, 295
one-first enumeration, 110
OPP, 346
optical axis, 94
optical center, 92
optical ray, 112
optimal triangulation, 247
orientation of a line, 42
orthogonal Procrustes problem, 346
outliers, 262
over-fitting, 185

P-normalization, 29
P3P, 244
panorama image, 296
panorama stitching, 296
parameter space, 149
parameterization of a transformation, 50
parametric representation, 19
perspective n-point problem, 241
pin-cushion distortion, 285
pinhole camera, 91, 93
pinhole perspective, 91
pixel coordinates, 101
pixel density, 105
pixel grid, 108
pixel value, 109
pixels, 93
Plücker coordinates of 2D line, 46
Plücker coordinates of 3D line, 67
consistent, 70
internal constraint, 70
plumb bob distortion, 287
PnP, 241
point at infinity, 42
point cloud, 322
point normalization, 29
points of interest, 186, 195
pose, 104
pre-conditioning, 207
principal axis, 94
principal line, 94
principal plane, 94
principal point, 94
projection, 83
projection line, 83, 112
projection plane, 116
projection point, 83
projective elements, 330
projective reconstruction, 135
projective space, 330
projectivity, 83

proper line, 67
proper lines, 41
proper points, 41
pseudo-inverse, 337
    full rank, 337
pure quaternion, 334
putative correspondences, 314

quaternion, 332
    inverse, 334
    pure, 334
quaternion sandwich product, 158
quaternionic embedding of $\mathbb{R}^3$, 158
quaternionic embedding of $SO(3)$, 159

radial distortion function, 284
Random Sample Consensus, 266
RANSAC, 266
re-mapping of the residual vector, 221
re-normalize, 203
re-parameterization, 219
reconstruction, 134
rectified stereo rig, 123, 136
rectifying homographies, 138
reference image, 297
registration, 237
representative of a projective element, 329
reprojection error, 317
residual, 363
residual error, 175
residual vector, 216
right inverse, 338
right singular vectors, 341
rigid transformation, 53
    estimation, 235
rigid transformation group, 53
robust errors, 263
robust estimation, 261, 262
    essential matrix, 274
    fundamental matrix, 273
    homography, 272
Rodrigues' rotation formula, 151, 152
rotation, 148
rotation matrix
    internal constraint, 148
row compression, 344

SAD, 179
sandwich product, 82
Schur complement, 340
Schur complement trick, 326
$SE(2)$, 53
$SE(3)$, 79
SfM, 314
shearing, 58
signed distance, 37
similarity reconstruction, 135
similarity transformations, 54
singular value decomposition, 340
singular values, 341
singularity, 150
skewing, 58
slope, 20
solution space, 197
SOPP, 233
special Euclidean transformation group
    in $\mathbb{E}^2$, 53
    in $\mathbb{E}^3$, 79
special orthogonal Procrustes problem, 233
special QR-factorization, 356
special SVD, 347
SSD, 179
SSVD, 347
standard deviation, 188
standard Plücker coordinates, 69
step length, 360
stereo camera, 121
stereo rectification, 123
stereo rig, 121, 123
structure from motion, 314
SVD, 340
SVD profile, 199

Tait-Bryan angles, 162
thin-prism distortion, 287
three-angle representation, 162
total least squares, 176
translation group, 52
trial set, 265
triangulation, 117, 123, 134, 245
twisted pair, 166
twisted rotations, 142, 166

unbiased estimate, 209
unbiased noise, 188
uncalibrated epipolar geometry, 121, 131
uniform noise, 188
unique representation, 149
unit quaternion, 334
unperturbed data, 187

variances, 175
vector product, 335
vectorization, 194, 211
virtual image plane, 97
visibility function, 317
visual appearance, 270

Wahba's problem, 232
world coordinate system, 98

zero-first enumeration, 110