Camera Calibration and 3D Reconstruction

Modules

- **Fisheye camera model**
- **C API**

Classes

struct	**cv::CirclesGridFinderParameters**
struct	**cv::CirclesGridFinderParameters2**
class	**cv::StereoBM** Class for computing stereo correspondence using the block matching algorithm, introduced and contributed to OpenCV by K. Konolige. More...
class	**cv::StereoMatcher** The base class for stereo correspondence algorithms. More...
class	**cv::StereoSGBM** The class implements the modified H. Hirschmuller algorithm **[86]** that differs from the original one as follows: More...

Enumerations

enum {
cv::LMEDS = 4,
cv::RANSAC = 8,
cv::RHO = 16
}
type of the robust estimation algorithm More...

enum {
cv::SOLVEPNP_ITERATIVE = 0,
cv::SOLVEPNP_EPNP = 1,
cv::SOLVEPNP_P3P = 2,
cv::SOLVEPNP_DLS = 3,
cv::SOLVEPNP_UPNP = 4,
cv::SOLVEPNP_AP3P = 5,
cv::SOLVEPNP_MAX_COUNT
}

enum {
cv::CALIB_CB_ADAPTIVE_THRESH = 1,
cv::CALIB_CB_NORMALIZE_IMAGE = 2,
cv::CALIB_CB_FILTER_QUADS = 4,
cv::CALIB_CB_FAST_CHECK = 8
}

enum {
cv::CALIB_CB_SYMMETRIC_GRID = 1,
cv::CALIB_CB_ASYMMETRIC_GRID = 2,
cv::CALIB_CB_CLUSTERING = 4
}

enum {
cv::CALIB_USE_INTRINSIC_GUESS = 0x00001,
cv::CALIB_FIX_ASPECT_RATIO = 0x00002,
cv::CALIB_FIX_PRINCIPAL_POINT = 0x00004,
cv::CALIB_ZERO_TANGENT_DIST = 0x00008,
cv::CALIB_FIX_FOCAL_LENGTH = 0x00010,
cv::CALIB_FIX_K1 = 0x00020,
cv::CALIB_FIX_K2 = 0x00040,
cv::CALIB_FIX_K3 = 0x00080,
cv::CALIB_FIX_K4 = 0x00800,
cv::CALIB_FIX_K5 = 0x01000,
cv::CALIB_FIX_K6 = 0x02000,
cv::CALIB_RATIONAL_MODEL = 0x04000,
cv::CALIB_THIN_PRISM_MODEL = 0x08000,
cv::CALIB_FIX_S1_S2_S3_S4 = 0x10000,
cv::CALIB_TILTED_MODEL = 0x40000,
cv::CALIB_FIX_TAUX_TAUY = 0x80000,
cv::CALIB_USE_QR = 0x100000,
cv::CALIB_FIX_TANGENT_DIST = 0x200000,
cv::CALIB_FIX_INTRINSIC = 0x00100,
cv::CALIB_SAME_FOCAL_LENGTH = 0x00200,
cv::CALIB_ZERO_DISPARITY = 0x00400,

cv::CALIB_USE_LU = (1 << 17),
cv::CALIB_USE_EXTRINSIC_GUESS = (1 << 22)
}

enum {
cv::FM_7POINT = 1,
cv::FM_8POINT = 2,
cv::FM_LMEDS = 4,
cv::FM_RANSAC = 8
}
the algorithm for finding fundamental matrix More...

Functions

double	**cv::calibrateCamera** (InputArrayOfArrays objectPoints, InputArrayOfArrays imagePoints, Size imageSize, InputOutputArray cameraMatrix, InputOutputArray distCoeffs, OutputArrayOfArrays rvecs, OutputArrayOfArrays tvecs, OutputArray stdDeviationsIntrinsics, OutputArray stdDeviationsExtrinsics, OutputArray perViewErrors, int flags=0, TermCriteria criteria=TermCriteria(TermCriteria::COUNT+TermCriteria::EPS, 30, DBL_EPSILON)) Finds the camera intrinsic and extrinsic parameters from several views of a calibration pattern. More...
double	**cv::calibrateCamera** (InputArrayOfArrays objectPoints, InputArrayOfArrays imagePoints, Size imageSize, InputOutputArray cameraMatrix, InputOutputArray distCoeffs, OutputArrayOfArrays rvecs, OutputArrayOfArrays tvecs, int flags=0, TermCriteria criteria=TermCriteria(TermCriteria::COUNT+TermCriteria::EPS, 30, DBL_EPSILON))
void	**cv::calibrationMatrixValues** (InputArray cameraMatrix, Size imageSize, double apertureWidth, double apertureHeight, double &fovx, double &fovy, double &focalLength, Point2d &principalPoint, double &aspectRatio) Computes useful camera characteristics from the camera matrix. More...
void	**cv::composeRT** (InputArray rvec1, InputArray tvec1, InputArray rvec2, InputArray tvec2, OutputArray rvec3, OutputArray tvec3, OutputArray dr3dr1=noArray(), OutputArray dr3dt1=noArray(), OutputArray dr3dr2=noArray(), OutputArray dr3dt2=noArray(), OutputArray dt3dr1=noArray(), OutputArray dt3dt1=noArray(), OutputArray dt3dr2=noArray(), OutputArray dt3dt2=noArray()) Combines two rotation-and-shift transformations. More...
void	**cv::computeCorrespondEpilines** (InputArray points, int whichImage, InputArray F, OutputArray lines) For points in an image of a stereo pair, computes the corresponding epilines in the other image. More...
void	**cv::convertPointsFromHomogeneous** (InputArray src, OutputArray dst) Converts points from homogeneous to Euclidean space. More...
void	**cv::convertPointsHomogeneous** (InputArray src, OutputArray dst) Converts points to/from homogeneous coordinates. More...
void	**cv::convertPointsToHomogeneous** (InputArray src, OutputArray dst) Converts points from Euclidean to homogeneous space. More...
void	**cv::correctMatches** (InputArray F, InputArray points1, InputArray points2, OutputArray newPoints1, OutputArray newPoints2) Refines coordinates of corresponding points. More...
void	**cv::decomposeEssentialMat** (InputArray E, OutputArray R1, OutputArray R2, OutputArray t) Decompose an essential matrix to possible rotations and translation. More...
int	**cv::decomposeHomographyMat** (InputArray H, InputArray K, OutputArrayOfArrays rotations, OutputArrayOfArrays translations, OutputArrayOfArrays normals) Decompose a homography matrix to rotation(s), translation(s) and plane normal(s). More...
void	**cv::decomposeProjectionMatrix** (InputArray projMatrix, OutputArray cameraMatrix, OutputArray rotMatrix, OutputArray transVect, OutputArray rotMatrixX=noArray(), OutputArray rotMatrixY=noArray(), OutputArray rotMatrixZ=noArray(), OutputArray eulerAngles=noArray()) Decomposes a projection matrix into a rotation matrix and a camera matrix. More...
void	**cv::drawChessboardCorners** (InputOutputArray image, Size patternSize, InputArray corners, bool patternWasFound) Renders the detected chessboard corners. More...
cv::Mat	**cv::estimateAffine2D** (InputArray from, InputArray to, OutputArray inliers=noArray(), int method=RANSAC, double ransacReprojThreshold=3, size_t maxIters=2000, double confidence=0.99, size_t refineIters=10) Computes an optimal affine transformation between two 2D point sets. More...
int	**cv::estimateAffine3D** (InputArray src, InputArray dst, OutputArray out, OutputArray inliers, double ransacThreshold=3, double confidence=0.99) Computes an optimal affine transformation between two 3D point sets. More...
cv::Mat	**cv::estimateAffinePartial2D** (InputArray from, InputArray to, OutputArray inliers=noArray(), int method=RANSAC, double ransacReprojThreshold=3, size_t maxIters=2000, double confidence=0.99, size_t refineIters=10) Computes an optimal limited affine transformation with 4 degrees of freedom between two 2D point sets. More...
void	**cv::filterHomographyDecompByVisibleRefpoints** (InputArrayOfArrays rotations, InputArrayOfArrays normals, InputArray beforePoints, InputArray afterPoints, OutputArray possibleSolutions, InputArray pointsMask=noArray()) Filters homography decompositions based on additional information. More...
void	**cv::filterSpeckles** (InputOutputArray img, double newVal, int maxSpeckleSize, double maxDiff, InputOutputArray buf=noArray()) Filters off small noise blobs (speckles) in the disparity map. More...
bool	**cv::find4QuadCornerSubpix** (InputArray img, InputOutputArray corners, Size region_size) finds subpixel-accurate positions of the chessboard corners More...

bool	**cv::findChessboardCorners** (**InputArray** image, **Size** patternSize, **OutputArray** corners, int flags=**CALIB_CB_ADAPTIVE_THRESH+CALIB_CB_NORMALIZE_IMAGE**) Finds the positions of internal corners of the chessboard. More...
bool	**cv::findCirclesGrid** (**InputArray** image, **Size** patternSize, **OutputArray** centers, int flags, const **Ptr**< **FeatureDetector** > &blobDetector, **CirclesGridFinderParameters** parameters) Finds centers in the grid of circles. More...
bool	**cv::findCirclesGrid** (**InputArray** image, **Size** patternSize, **OutputArray** centers, int flags=**CALIB_CB_SYMMETRIC_GRID**, const **Ptr**< **FeatureDetector** > &blobDetector=**SimpleBlobDetector::create**())
bool	**cv::findCirclesGrid2** (**InputArray** image, **Size** patternSize, **OutputArray** centers, int flags, const **Ptr**< **FeatureDetector** > &blobDetector, **CirclesGridFinderParameters2** parameters)
Mat	**cv::findEssentialMat** (**InputArray** points1, **InputArray** points2, **InputArray** cameraMatrix, int method=**RANSAC**, double prob=0.999, double **threshold**=1.0, **OutputArray** mask=**noArray**()) Calculates an essential matrix from the corresponding points in two images. More...
Mat	**cv::findEssentialMat** (**InputArray** points1, **InputArray** points2, double focal=1.0, **Point2d** pp=**Point2d**(0, 0), int method=**RANSAC**, double prob=0.999, double **threshold**=1.0, **OutputArray** mask=**noArray**())
Mat	**cv::findFundamentalMat** (**InputArray** points1, **InputArray** points2, int method=**FM_RANSAC**, double ransacReprojThreshold=3., double confidence=0.99, **OutputArray** mask=**noArray**()) Calculates a fundamental matrix from the corresponding points in two images. More...
Mat	**cv::findFundamentalMat** (**InputArray** points1, **InputArray** points2, **OutputArray** mask, int method=**FM_RANSAC**, double ransacReprojThreshold=3., double confidence=0.99)
Mat	**cv::findHomography** (**InputArray** srcPoints, **InputArray** dstPoints, int method=0, double ransacReprojThreshold=3, **OutputArray** mask=**noArray**(), const int maxIters=2000, const double confidence=0.995) Finds a perspective transformation between two planes. More...
Mat	**cv::findHomography** (**InputArray** srcPoints, **InputArray** dstPoints, **OutputArray** mask, int method=0, double ransacReprojThreshold=3)
Mat	**cv::getOptimalNewCameraMatrix** (**InputArray** cameraMatrix, **InputArray** distCoeffs, **Size** imageSize, double alpha, **Size** newImgSize=**Size**(), **Rect** *validPixROI=0, bool centerPrincipalPoint=false) Returns the new camera matrix based on the free scaling parameter. More...
Rect	**cv::getValidDisparityROI** (**Rect** roi1, **Rect** roi2, int minDisparity, int numberOfDisparities, int SADWindowSize) computes valid disparity ROI from the valid ROIs of the rectified images (that are returned by **cv::stereoRectify()**) More...
Mat	**cv::initCameraMatrix2D** (**InputArrayOfArrays** objectPoints, **InputArrayOfArrays** imagePoints, **Size** imageSize, double aspectRatio=1.0) Finds an initial camera matrix from 3D-2D point correspondences. More...
void	**cv::matMulDeriv** (**InputArray** A, **InputArray** B, **OutputArray** dABdA, **OutputArray** dABdB) Computes partial derivatives of the matrix product for each multiplied matrix. More...
void	**cv::projectPoints** (**InputArray** objectPoints, **InputArray** rvec, **InputArray** tvec, **InputArray** cameraMatrix, **InputArray** distCoeffs, **OutputArray** imagePoints, **OutputArray** jacobian=**noArray**(), double aspectRatio=0) Projects 3D points to an image plane. More...
int	**cv::recoverPose** (**InputArray** E, **InputArray** points1, **InputArray** points2, **InputArray** cameraMatrix, **OutputArray** R, **OutputArray** t, **InputOutputArray** mask=**noArray**()) Recover relative camera rotation and translation from an estimated essential matrix and the corresponding points in two images, using cheirality check. Returns the number of inliers which pass the check. More...
int	**cv::recoverPose** (**InputArray** E, **InputArray** points1, **InputArray** points2, **OutputArray** R, **OutputArray** t, double focal=1.0, **Point2d** pp=**Point2d**(0, 0), **InputOutputArray** mask=**noArray**())
int	**cv::recoverPose** (**InputArray** E, **InputArray** points1, **InputArray** points2, **InputArray** cameraMatrix, **OutputArray** R, **OutputArray** t, double distanceThresh, **InputOutputArray** mask=**noArray**(), **OutputArray** triangulatedPoints=**noArray**())
float	**cv::rectify3Collinear** (**InputArray** cameraMatrix1, **InputArray** distCoeffs1, **InputArray** cameraMatrix2, **InputArray** distCoeffs2, **InputArray** cameraMatrix3, **InputArray** distCoeffs3, **InputArrayOfArrays** imgpt1, **InputArrayOfArrays** imgpt3, **Size** imageSize, **InputArray** R12, **InputArray** T12, **InputArray** R13, **InputArray** T13, **OutputArray** R1, **OutputArray** R2, **OutputArray** R3, **OutputArray** P1, **OutputArray** P2, **OutputArray** P3, **OutputArray** Q, double alpha, **Size** newImgSize, **Rect** *roi1, **Rect** *roi2, int flags) computes the rectification transformations for 3-head camera, where all the heads are on the same line. More...
void	**cv::reprojectImageTo3D** (**InputArray** disparity, **OutputArray** _3dImage, **InputArray** Q, bool handleMissingValues=false, int ddepth=-1) Reprojects a disparity image to 3D space. More...
void	**cv::Rodrigues** (**InputArray** src, **OutputArray** dst, **OutputArray** jacobian=**noArray**()) Converts a rotation matrix to a rotation vector or vice versa. More...
Vec3d	**cv::RQDecomp3x3** (**InputArray** src, **OutputArray** mtxR, **OutputArray** mtxQ, **OutputArray** Qx=**noArray**(), **OutputArray** Qy=**noArray**(), **OutputArray** Qz=**noArray**()) Computes an RQ decomposition of 3x3 matrices. More...
double	**cv::sampsonDistance** (**InputArray** pt1, **InputArray** pt2, **InputArray** F) Calculates the Sampson Distance between two points. More...
int	**cv::solveP3P** (**InputArray** objectPoints, **InputArray** imagePoints, **InputArray** cameraMatrix, **InputArray** distCoeffs, **OutputArrayOfArrays** rvecs, **OutputArrayOfArrays** tvecs, int flags) Finds an object pose from 3 3D-2D point correspondences. More...
bool	**cv::solvePnP** (**InputArray** objectPoints, **InputArray** imagePoints, **InputArray** cameraMatrix, **InputArray** distCoeffs, **OutputArray** rvec, **OutputArray** tvec, bool useExtrinsicGuess=false, int flags=**SOLVEPNP_ITERATIVE**) Finds an object pose from 3D-2D point correspondences. More...

bool	**cv::solvePnPRansac** (**InputArray** objectPoints, **InputArray** imagePoints, **InputArray** cameraMatrix, **InputArray** distCoeffs, **OutputArray** rvec, **OutputArray** tvec, bool useExtrinsicGuess=false, int iterationsCount=100, float reprojectionError=8.0, double confidence=0.99, **OutputArray** inliers=**noArray**(), int flags=**SOLVEPNP_ITERATIVE**) Finds an object pose from 3D-2D point correspondences using the RANSAC scheme. More...
double	**cv::stereoCalibrate** (**InputArrayOfArrays** objectPoints, **InputArrayOfArrays** imagePoints1, **InputArrayOfArrays** imagePoints2, **InputOutputArray** cameraMatrix1, **InputOutputArray** distCoeffs1, **InputOutputArray** cameraMatrix2, **InputOutputArray** distCoeffs2, **Size** imageSize, **InputOutputArray** R, **InputOutputArray T**, **OutputArray** E, **OutputArray** F, **OutputArray** perViewErrors, int flags=**CALIB_FIX_INTRINSIC**, **TermCriteria** criteria=**TermCriteria**(**TermCriteria::COUNT**+**TermCriteria::EPS**, 30, 1e-6)) Calibrates the stereo camera. More...
double	**cv::stereoCalibrate** (**InputArrayOfArrays** objectPoints, **InputArrayOfArrays** imagePoints1, **InputArrayOfArrays** imagePoints2, **InputOutputArray** cameraMatrix1, **InputOutputArray** distCoeffs1, **InputOutputArray** cameraMatrix2, **InputOutputArray** distCoeffs2, **Size** imageSize, **OutputArray** R, **OutputArray T**, **OutputArray** E, **OutputArray** F, int flags=**CALIB_FIX_INTRINSIC**, **TermCriteria** criteria=**TermCriteria**(**TermCriteria::COUNT**+**TermCriteria::EPS**, 30, 1e-6))
void	**cv::stereoRectify** (**InputArray** cameraMatrix1, **InputArray** distCoeffs1, **InputArray** cameraMatrix2, **InputArray** distCoeffs2, **Size** imageSize, **InputArray** R, **InputArray T**, **OutputArray** R1, **OutputArray** R2, **OutputArray** P1, **OutputArray** P2, **OutputArray** Q, int flags=**CALIB_ZERO_DISPARITY**, double alpha=-1, **Size** newImageSize=**Size**(), **Rect** *validPixROI1=0, **Rect** *validPixROI2=0) Computes rectification transforms for each head of a calibrated stereo camera. More...
bool	**cv::stereoRectifyUncalibrated** (**InputArray** points1, **InputArray** points2, **InputArray** F, **Size** imgSize, **OutputArray** H1, **OutputArray** H2, double **threshold**=5) Computes a rectification transform for an uncalibrated stereo camera. More...
void	**cv::triangulatePoints** (**InputArray** projMatr1, **InputArray** projMatr2, **InputArray** projPoints1, **InputArray** projPoints2, **OutputArray** points4D) Reconstructs points by triangulation. More...
void	**cv::validateDisparity** (**InputOutputArray** disparity, **InputArray** cost, int minDisparity, int numberOfDisparities, int disp12MaxDisp=1) validates disparity using the left-right check. The matrix "cost" should be computed by the stereo correspondence algorithm More...

Detailed Description

The functions in this section use a so-called pinhole camera model. In this model, a scene view is formed by projecting 3D points into the image plane using a perspective transformation.

$$s\ m' = A[R|t]M'$$

or

$$s \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_1 \\ r_{21} & r_{22} & r_{23} & t_2 \\ r_{31} & r_{32} & r_{33} & t_3 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

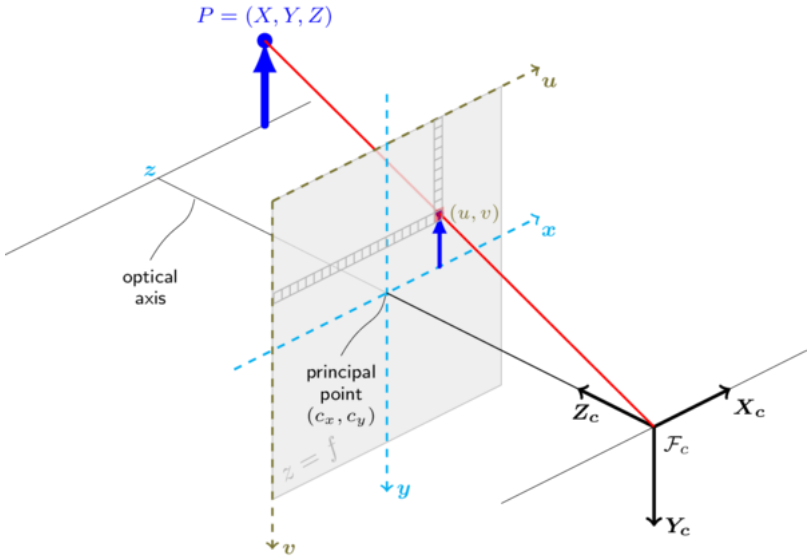
where:

- (X, Y, Z) are the coordinates of a 3D point in the world coordinate space
- (u, v) are the coordinates of the projection point in pixels
- A is a camera matrix, or a matrix of intrinsic parameters
- (cx, cy) is a principal point that is usually at the image center
- fx, fy are the focal lengths expressed in pixel units.

Thus, if an image from the camera is scaled by a factor, all of these parameters should be scaled (multiplied/divided, respectively) by the same factor. The matrix of intrinsic parameters does not depend on the scene viewed. So, once estimated, it can be re-used as long as the focal length is fixed (in case of zoom lens). The joint rotation-translation matrix $[R|t]$ is called a matrix of extrinsic parameters. It is used to describe the camera motion around a static scene, or vice versa, rigid motion of an object in front of a still camera. That is, $[R|t]$ translates coordinates of a point (X, Y, Z) to a coordinate system, fixed with respect to the camera. The transformation above is equivalent to the following (when $z \neq 0$):

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = R \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + t$$
$$x' = x/z$$
$$y' = y/z$$
$$u = f_x * x' + c_x$$
$$v = f_y * y' + c_y$$

The following figure illustrates the pinhole camera model.



Pinhole camera model

Real lenses usually have some distortion, mostly radial distortion and slight tangential distortion. So, the above model is extended as:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = R \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + t$$

$$x' = x/z$$

$$y' = y/z$$

$$x'' = x' \frac{1+k_1 r^2+k_2 r^4+k_3 r^6}{1+k_4 r^2+k_5 r^4+k_6 r^6} + 2p_1 x' y' + p_2(r^2+2x'^2) + s_1 r^2 + s_2 r^4$$

$$y'' = y' \frac{1+k_1 r^2+k_2 r^4+k_3 r^6}{1+k_4 r^2+k_5 r^4+k_6 r^6} + p_1(r^2+2y'^2) + 2p_2 x' y' + s_3 r^2 + s_4 r^4$$

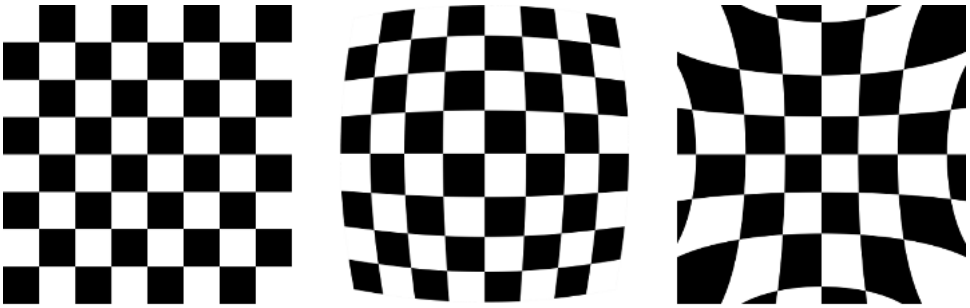
$$\text{where} \quad r^2 = x'^2 + y'^2$$

$$u = f_x * x'' + c_x$$

$$v = f_y * y'' + c_y$$

k_1, k_2, k_3, k_4, k_5, and k_6 are radial distortion coefficients. p_1 and p_2 are tangential distortion coefficients. s_1, s_2, s_3, and s_4, are the thin prism distortion coefficients. Higher-order coefficients are not considered in OpenCV.

The next figure shows two common types of radial distortion: barrel distortion (typically $k_1 > 0$) and pincushion distortion (typically $k_1 < 0$).



In some cases the image sensor may be tilted in order to focus an oblique plane in front of the camera (Scheimpfug condition). This can be useful for particle image velocimetry (PIV) or triangulation with a laser fan. The tilt causes a perspective distortion of x'' and y''. This distortion can be modelled in the following way, see e.g. **[117]**.

$$s \begin{bmatrix} x''' \\ y''' \\ 1 \end{bmatrix} = \begin{bmatrix} R_{33}(\tau_x, \tau_y) & 0 & -R_{13}(\tau_x, \tau_y) \\ 0 & R_{33}(\tau_x, \tau_y) & -R_{23}(\tau_x, \tau_y) \\ 0 & 0 & 1 \end{bmatrix} R(\tau_x, \tau_y) \begin{bmatrix} x'' \\ y'' \\ 1 \end{bmatrix}$$

$$u = f_x * x''' + c_x$$

$$v = f_y * y''' + c_y$$

where the matrix $R(\tau_x, \tau_y)$ is defined by two rotations with angular parameter τ_x and τ_y, respectively,

$$R(\tau_x, \tau_y) = \begin{bmatrix} \cos(\tau_y) & 0 & -\sin(\tau_y) \\ 0 & 1 & 0 \\ \sin(\tau_y) & 0 & \cos(\tau_y) \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\tau_x) & \sin(\tau_x) \\ 0 & -\sin(\tau_x) & \cos(\tau_x) \end{bmatrix} = \begin{bmatrix} \cos(\tau_y) & \sin(\tau_y)\sin(\tau_x) & -\sin(\tau_y)\cos(\tau_x) \\ 0 & \cos(\tau_x) & \sin(\tau_x) \\ \sin(\tau_y) & -\cos(\tau_y)\sin(\tau_x) & \cos(\tau_y)\cos(\tau_x) \end{bmatrix}.$$

In the functions below the coefficients are passed or returned as

$$(k_1, k_2, p_1, p_2[, k_3[, k_4, k_5, k_6[, s_1, s_2, s_3, s_4[, \tau_x, \tau_y]]]])$$

vector. That is, if the vector contains four elements, it means that $k_3 = 0$. The distortion coefficients do not depend on the scene viewed. Thus, they also belong to the intrinsic camera parameters. And they remain the same regardless of the captured image resolution. If, for example, a camera has been calibrated on images of 320 x 240 resolution, absolutely the same distortion coefficients can be used for 640 x 480 images from the same camera while f_x , f_y , c_x , and c_y need to be scaled appropriately.

The functions below use the above model to do the following:

- Project 3D points to the image plane given intrinsic and extrinsic parameters.
- Compute extrinsic parameters given intrinsic parameters, a few 3D points, and their projections.
- Estimate intrinsic and extrinsic camera parameters from several views of a known calibration pattern (every view is described by several 3D-2D point correspondences).
- Estimate the relative position and orientation of the stereo camera "heads" and compute the rectification* transformation that makes the camera optical axes parallel.

Note

- A calibration sample for 3 cameras in horizontal position can be found at opencv_source_code/samples/cpp/3calibration.cpp
  - A calibration sample based on a sequence of images can be found at opencv_source_code/samples/cpp/calibration.cpp
  - A calibration sample in order to do 3D reconstruction can be found at opencv_source_code/samples/cpp/build3dmodel.cpp
  - A calibration sample of an artificially generated camera and chessboard patterns can be found at opencv_source_code/samples/cpp/calibration_artificial.cpp
  - A calibration example on stereo calibration can be found at opencv_source_code/samples/cpp/stereo_calib.cpp
  - A calibration example on stereo matching can be found at opencv_source_code/samples/cpp/stereo_match.cpp
  - (Python) A camera calibration sample can be found at opencv_source_code/samples/python/calibrate.py

Enumeration Type Documentation

§ anonymous enum

anonymous enum

type of the robust estimation algorithm

Enumerator	
LMEDS Python: cv.LMEDS	least-median of squares algorithm
RANSAC Python: cv.RANSAC	RANSAC algorithm.
RHO Python: cv.RHO	RHO algorithm.

§ anonymous enum

anonymous enum

Enumerator	
SOLVEPNP_ITERATIVE Python: cv.SOLVEPNP_ITERATIVE	
SOLVEPNP_EPNP Python: cv.SOLVEPNP_EPNP	EPnP: Efficient Perspective-n-Point Camera Pose Estimation **[107]**.
SOLVEPNP_P3P Python: cv.SOLVEPNP_P3P	Complete Solution Classification for the Perspective-Three-Point Problem **[64]**.
SOLVEPNP_DLS Python: cv.SOLVEPNP_DLS	A Direct Least-Squares (DLS) Method for PnP **[84]**.
SOLVEPNP_UPNP Python: cv.SOLVEPNP_UPNP	Exhaustive Linearization for Robust Camera Pose and Focal Length Estimation **[148]**.
SOLVEPNP_AP3P Python: cv.SOLVEPNP_AP3P	An Efficient Algebraic Solution to the Perspective-Three-Point Problem **[96]**.
SOLVEPNP_MAX_COUNT Python: cv.SOLVEPNP_MAX_COUNT	Used for count.

§ anonymous enum

anonymous enum

Enumerator
CALIB_CB_ADAPTIVE_THRESH Python: cv.CALIB_CB_ADAPTIVE_THRESH
CALIB_CB_NORMALIZE_IMAGE Python: cv.CALIB_CB_NORMALIZE_IMAGE
CALIB_CB_FILTER_QUADS Python: cv.CALIB_CB_FILTER_QUADS
CALIB_CB_FAST_CHECK Python: cv.CALIB_CB_FAST_CHECK

§ anonymous enum

anonymous enum

Enumerator
CALIB_CB_SYMMETRIC_GRID Python: cv.CALIB_CB_SYMMETRIC_GRID
CALIB_CB_ASYMMETRIC_GRID Python: cv.CALIB_CB_ASYMMETRIC_GRID
CALIB_CB_CLUSTERING Python: cv.CALIB_CB_CLUSTERING

§ anonymous enum

anonymous enum

Enumerator	
CALIB_USE_INTRINSIC_GUESS Python: cv.CALIB_USE_INTRINSIC_GUESS	
CALIB_FIX_ASPECT_RATIO Python: cv.CALIB_FIX_ASPECT_RATIO	
CALIB_FIX_PRINCIPAL_POINT Python: cv.CALIB_FIX_PRINCIPAL_POINT	
CALIB_ZERO_TANGENT_DIST Python: cv.CALIB_ZERO_TANGENT_DIST	
CALIB_FIX_FOCAL_LENGTH Python: cv.CALIB_FIX_FOCAL_LENGTH	
CALIB_FIX_K1 Python: cv.CALIB_FIX_K1	
CALIB_FIX_K2 Python: cv.CALIB_FIX_K2	
CALIB_FIX_K3 Python: cv.CALIB_FIX_K3	
CALIB_FIX_K4 Python: cv.CALIB_FIX_K4	
CALIB_FIX_K5 Python: cv.CALIB_FIX_K5	
CALIB_FIX_K6 Python: cv.CALIB_FIX_K6	
CALIB_RATIONAL_MODEL Python: cv.CALIB_RATIONAL_MODEL	
CALIB_THIN_PRISM_MODEL Python: cv.CALIB_THIN_PRISM_MODEL	
CALIB_FIX_S1_S2_S3_S4 Python: cv.CALIB_FIX_S1_S2_S3_S4	
CALIB_TILTED_MODEL Python: cv.CALIB_TILTED_MODEL	
CALIB_FIX_TAUX_TAUY Python: cv.CALIB_FIX_TAUX_TAUY	
CALIB_USE_QR Python: cv.CALIB_USE_QR	use QR instead of **SVD** decomposition for solving. Faster but potentially less precise
CALIB_FIX_TANGENT_DIST Python: cv.CALIB_FIX_TANGENT_DIST	
CALIB_FIX_INTRINSIC Python: cv.CALIB_FIX_INTRINSIC	
CALIB_SAME_FOCAL_LENGTH Python: cv.CALIB_SAME_FOCAL_LENGTH	
CALIB_ZERO_DISPARITY Python: cv.CALIB_ZERO_DISPARITY	
CALIB_USE_LU Python: cv.CALIB_USE_LU	use LU instead of **SVD** decomposition for solving. much faster but potentially less precise
CALIB_USE_EXTRINSIC_GUESS Python: cv.CALIB_USE_EXTRINSIC_GUESS	for stereoCalibrate

§ anonymous enum

anonymous enum

the algorithm for finding fundamental matrix

Enumerator	
FM_7POINT Python: cv.FM_7POINT	7-point algorithm
FM_8POINT Python: cv.FM_8POINT	8-point algorithm
FM_LMEDS Python: cv.FM_LMEDS	least-median algorithm. 7-point algorithm is used.
FM_RANSAC Python: cv.FM_RANSAC	RANSAC algorithm. It needs at least 15 points. 7-point algorithm is used.

Function Documentation

§ calibrateCamera() [1/2]

```
double cv::calibrateCamera ( InputArrayOfArrays  objectPoints,
                             InputArrayOfArrays  imagePoints,
                             Size                imageSize,
                             InputOutputArray    cameraMatrix,
                             InputOutputArray    distCoeffs,
                             OutputArrayOfArrays rvecs,
                             OutputArrayOfArrays tvecs,
                             OutputArray         stdDeviationsIntrinsics,
                             OutputArray         stdDeviationsExtrinsics,
                             OutputArray         perViewErrors,
                             int                 flags = 0,
                             TermCriteria        criteria = TermCriteria(TermCriteria::COUNT+TermCriteria::EPS, 30, DBL_EPSILON)
                           )
```

Python:

```
retval, cameraMatrix, distCoeffs, rvecs, tvecs = cv.calibrateCamera( objectPoints, imagePoints, imageSize, cameraMatrix, distCoeffs[, rvecs[, tvecs[, flags[, criteria]]]]
retval, cameraMatrix, distCoeffs, rvecs, tvecs, stdDeviationsIntrinsics, stdDeviationsExtrinsics, perViewErrors = cv.calibrateCameraExtended( objectPoints, imagePoints, imageSize, cameraMatrix, distCoeffs[, rvecs[, tvecs[, stdDeviationsIntrinsics[, std
```

Finds the camera intrinsic and extrinsic parameters from several views of a calibration pattern.

Parameters

objectPoints	In the new interface it is a vector of vectors of calibration pattern points in the calibration pattern coordinate space (e.g. std::vector<s many elements as the number of the pattern views. If the same calibration pattern is shown in each view and it is fully visible, all the partially occluded patterns, or even different patterns in different views. Then, the vectors will be different. The points are 3D, but sir rig is planar, it may make sense to put the model to a XY coordinate plane so that Z-coordinate of each input object point is 0. In the different views are concatenated together.
imagePoints	In the new interface it is a vector of vectors of the projections of calibration pattern points (e.g. std::vector<std::vector<cv::Vec2f>>). imagePoints[i].size() must be equal to objectPoints[i].size() for each i. In the old interface all the vectors of object points from differe
imageSize	Size of the image used only to initialize the intrinsic camera matrix.
cameraMatrix	Output 3x3 floating-point camera matrix $A = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}$. If CV_CALIB_USE_INTRINSIC_GUESS and/or CALIB_FIX_ASP must be initialized before calling the function.
distCoeffs	Output vector of distortion coefficients $(k_1, k_2, p_1, p_2[, k_3[, k_4, k_5, k_6[, s_1, s_2, s_3, s_4[, \tau_x, \tau_y]]]])$ of 4, 5, 8, 12 or 14 elements.
rvecs	Output vector of rotation vectors (see Rodrigues) estimated for each pattern view (e.g. std::vector<cv::Mat>>). That is, each k-th ro translation vector (see the next output parameter description) brings the calibration pattern from the model coordinate space (in whi space, that is, a real position of the calibration pattern in the k-th pattern view (k=0.. *M* -1).
tvecs	Output vector of translation vectors estimated for each pattern view.
stdDeviationsIntrinsics	Output vector of standard deviations estimated for intrinsic parameters. Order of deviations values: $(f_x, f_y, c_x, c_y, k_1, k_2, p_1, p_2,$ parameters is not estimated, it's deviation is equals to zero.
stdDeviationsExtrinsics	Output vector of standard deviations estimated for extrinsic parameters. Order of deviations values: $(R_1, T_1, \dots, R_M, T_M)$ where concatenated 1x3 vectors.
perViewErrors	Output vector of the RMS re-projection error estimated for each pattern view.
flags	Different flags that may be zero or a combination of the following values:

- **CALIB_USE_INTRINSIC_GUESS** cameraMatrix contains valid initial values of fx, fy, cx, cy that are optimized further. Otherw imageSize is used), and focal distances are computed in a least-squares fashion. Note, that if intrinsic parameters are known extrinsic parameters. Use solvePnP instead.
- **CALIB_FIX_PRINCIPAL_POINT** The principal point is not changed during the global optimization. It stays at the center or at CALIB_USE_INTRINSIC_GUESS is set too.
- **CALIB_FIX_ASPECT_RATIO** The functions considers only fy as a free parameter. The ratio fx/fy stays the same as in the in CALIB_USE_INTRINSIC_GUESS is not set, the actual input values of fx and fy are ignored, only their ratio is computed and
- **CALIB_ZERO_TANGENT_DIST** Tangential distortion coefficients (p_1, p_2) are set to zeros and stay zero.
- **CALIB_FIX_K1,...,CALIB_FIX_K6** The corresponding radial distortion coefficient is not changed during the optimization. If C from the supplied distCoeffs matrix is used. Otherwise, it is set to 0.
- **CALIB_RATIONAL_MODEL** Coefficients k4, k5, and k6 are enabled. To provide the backward compatibility, this extra flag sh function use the rational model and return 8 coefficients. If the flag is not set, the function computes and returns only 5 distort
- **CALIB_THIN_PRISM_MODEL** Coefficients s1, s2, s3 and s4 are enabled. To provide the backward compatibility, this extra f function use the thin prism model and return 12 coefficients. If the flag is not set, the function computes and returns only 5 dis
- **CALIB_FIX_S1_S2_S3_S4** The thin prism distortion coefficients are not changed during the optimization. If CALIB_USE_INT supplied distCoeffs matrix is used. Otherwise, it is set to 0.

- **CALIB_TILTED_MODEL** Coefficients tauX and tauY are enabled. To provide the backward compatibility, this extra flag shoul use the tilted sensor model and return 14 coefficients. If the flag is not set, the function computes and returns only 5 distortior
- **CALIB_FIX_TAUX_TAUY** The coefficients of the tilted sensor model are not changed during the optimization. If CALIB_USE supplied distCoeffs matrix is used. Otherwise, it is set to 0.

criteria Termination criteria for the iterative optimization algorithm.

Returns

the overall RMS re-projection error.

The function estimates the intrinsic camera parameters and extrinsic parameters for each of the views. The algorithm is based on **[223]** and **[21]** . The coordinates of in each view must be specified. That may be achieved by using an object with a known geometry and easily detectable feature points. Such an object is called a calib support for a chessboard as a calibration rig (see findChessboardCorners). Currently, initialization of intrinsic parameters (when CALIB_USE_INTRINSIC_GUESS is patterns (where Z-coordinates of the object points must be all zeros). 3D calibration rigs can also be used as long as initial cameraMatrix is provided.

The algorithm performs the following steps:

- Compute the initial intrinsic parameters (the option only available for planar calibration patterns) or read them from the input parameters. The distortion coeffici CALIB_FIX_K? are specified.
- Estimate the initial camera pose as if the intrinsic parameters have been already known. This is done using solvePnP .
- Run the global Levenberg-Marquardt optimization algorithm to minimize the reprojection error, that is, the total sum of squared distances between the observe the current estimates for camera parameters and the poses) object points objectPoints. See projectPoints for details.

Note

If you use a non-square (=non-NxN) grid and findChessboardCorners for calibration, and calibrateCamera returns bad values (zero distortion coefficients, an i differences between f_x and f_y (ratios of 10:1 or more)), then you have probably used patternSize=cvSize(rows,cols) instead of using patternSize=cvSize(cols

See also

findChessboardCorners, **solvePnP**, **initCameraMatrix2D**, **stereoCalibrate**, **undistort**

§ calibrateCamera() [2/2]

```
double cv::calibrateCamera ( InputArrayOfArrays objectPoints,
                             InputArrayOfArrays imagePoints,
                             Size               imageSize,
                             InputOutputArray   cameraMatrix,
                             InputOutputArray   distCoeffs,
                             OutputArrayOfArrays rvecs,
                             OutputArrayOfArrays tvecs,
                             int                flags = 0,
                             TermCriteria       criteria = TermCriteria(TermCriteria::COUNT+TermCriteria::EPS, 30, DBL_EPSILON)
                           )
```

Python:

```
retval, cameraMatrix, distCoeffs, rvecs, tvecs = cv.calibrateCamera( objectPoints, imagePoints, imageSize, cameraMatrix, distCoeffs[, rvecs[, tvecs[, flags[, criteria]]]]
retval, cameraMatrix, distCoeffs, rvecs, tvecs, stdDeviationsIntrinsics, stdDeviationsExtrinsics, perViewErrors = cv.calibrateCameraExtended( objectPoints, imagePoints, imageSize, cameraMatrix, distCoeffs[, rvecs[, tvecs[, stdDeviationsIntrinsics[, std
```

§ calibrationMatrixValues()

```
void cv::calibrationMatrixValues ( InputArray  cameraMatrix,
                                   Size        imageSize,
                                   double      apertureWidth,
                                   double      apertureHeight,
                                   double &    fovx,
                                   double &    fovy,
                                   double &    focalLength,
                                   Point2d &   principalPoint,
                                   double &    aspectRatio
                                 )
```

Python:

```
fovx, fovy, focalLength, principalPoint, aspectRatio = cv.calibrationMatrixValues( cameraMatrix, imageSize, apertureWidth, apertureHeight )
```

Computes useful camera characteristics from the camera matrix.

Parameters

cameraMatrix	Input camera matrix that can be estimated by calibrateCamera or stereoCalibrate .
imageSize	Input image size in pixels.
apertureWidth	Physical width in mm of the sensor.
apertureHeight	Physical height in mm of the sensor.
fovx	Output field of view in degrees along the horizontal sensor axis.
fovy	Output field of view in degrees along the vertical sensor axis.
focalLength	Focal length of the lens in mm.
principalPoint	Principal point in mm.
aspectRatio	f_y/f_x

The function computes various useful camera characteristics from the previously estimated camera matrix.

Note

Do keep in mind that the unity measure 'mm' stands for whatever unit of measure one chooses for the chessboard pitch (it can thus be any value).

§ composeRT()

```
void cv::composeRT ( InputArray  rvec1,
                     InputArray  tvec1,
                     InputArray  rvec2,
                     InputArray  tvec2,
                     OutputArray rvec3,
                     OutputArray tvec3,
                     OutputArray dr3dr1 = noArray(),
                     OutputArray dr3dt1 = noArray(),
                     OutputArray dr3dr2 = noArray(),
                     OutputArray dr3dt2 = noArray(),
                     OutputArray dt3dr1 = noArray(),
                     OutputArray dt3dt1 = noArray(),
                     OutputArray dt3dr2 = noArray(),
                     OutputArray dt3dt2 = noArray()
                   )
```

Python:

```
rvec3, tvec3,
dr3dr1, dr3dt1,
dr3dr2, dr3dt2,      = cv.composeRT( rvec1, tvec1, rvec2, tvec2[, rvec3[, tvec3[, dr3dr1[, dr3dt1[, dr3dr2[, dr3dt2[, dt3dr1[, dt3dt1[, dt3dr2[, dt3dt2]]]]]]]]] ] )
dt3dr1, dt3dt1,
dt3dr2, dt3dt2
```

Combines two rotation-and-shift transformations.

Parameters

rvec1	First rotation vector.
tvec1	First translation vector.
rvec2	Second rotation vector.
tvec2	Second translation vector.
rvec3	Output rotation vector of the superposition.
tvec3	Output translation vector of the superposition.
dr3dr1	
dr3dt1	
dr3dr2	
dr3dt2	
dt3dr1	
dt3dt1	
dt3dr2	
dt3dt2	Optional output derivatives of rvec3 or tvec3 with regard to rvec1, rvec2, tvec1 and tvec2, respectively.

The functions compute:

$$\begin{array}{l} \texttt{rvec3} = \mathrm{rodrigues}^{-1}\left(\mathrm{rodrigues}(\texttt{rvec2}) \cdot \mathrm{rodrigues}(\texttt{rvec1})\right) \\ \texttt{tvec3} = \mathrm{rodrigues}(\texttt{rvec2}) \cdot \texttt{tvec1} + \texttt{tvec2} \end{array},$$

where $\mathrm{rodrigues}$ denotes a rotation vector to a rotation matrix transformation, and $\mathrm{rodrigues}^{-1}$ denotes the inverse transformation. See Rodrigues for details.

Also, the functions can compute the derivatives of the output vectors with regards to the input vectors (see matMulDeriv). The functions are used inside stereoCalibrate but can also be used in your own code where Levenberg-Marquardt or another gradient-based solver is used to optimize a function that contains a matrix multiplication.

§ computeCorrespondEpilines()

```
void cv::computeCorrespondEpilines ( InputArray  points,
                                     int         whichImage,
                                     InputArray  F,
                                     OutputArray lines
                                   )
```

Python:

```
lines = cv.computeCorrespondEpilines( points, whichImage, F[, lines] )
```

For points in an image of a stereo pair, computes the corresponding epilines in the other image.

Parameters

points	Input points. $N \times 1$ or $1 \times N$ matrix of type CV_32FC2 or vector<Point2f> .
whichImage	Index of the image (1 or 2) that contains the points .
F	Fundamental matrix that can be estimated using findFundamentalMat or stereoRectify .
lines	Output vector of the epipolar lines corresponding to the points in the other image. Each line $ax + by + c = 0$ is encoded by 3 numbers (a, b, c) .

For every point in one of the two images of a stereo pair, the function finds the equation of the corresponding epipolar line in the other image.

From the fundamental matrix definition (see findFundamentalMat), line $l_i^{(2)}$ in the second image for the point $p_i^{(1)}$ in the first image (when whichImage=1) is computed as:

$$l_i^{(2)} = F p_i^{(1)}$$

And vice versa, when whichImage=2, $l_i^{(1)}$ is computed from $p_i^{(2)}$ as:

$$l_i^{(1)} = F^T p_i^{(2)}$$

Line coefficients are defined up to a scale. They are normalized so that $a_i^2 + b_i^2 = 1$.

§ convertPointsFromHomogeneous()

```
void cv::convertPointsFromHomogeneous ( InputArray  src,
                                        OutputArray dst
                                      )
```

Python:

```
dst = cv.convertPointsFromHomogeneous( src[, dst] )
```

Converts points from homogeneous to Euclidean space.

Parameters

src	Input vector of N-dimensional points.
dst	Output vector of N-1-dimensional points.

The function converts points homogeneous to Euclidean space using perspective projection. That is, each point (x1, x2, ... x(n-1), xn) is converted to (x1/xn, x2/xn, ..., x(n-1)/xn). When xn=0, the output point coordinates will be (0,0,0,...).

§ convertPointsHomogeneous()

```
void cv::convertPointsHomogeneous ( InputArray  src,
                                    OutputArray dst
                                  )
```

Converts points to/from homogeneous coordinates.

Parameters

src	Input array or vector of 2D, 3D, or 4D points.
dst	Output vector of 2D, 3D, or 4D points.

The function converts 2D or 3D points from/to homogeneous coordinates by calling either convertPointsToHomogeneous or convertPointsFromHomogeneous.

Note

The function is obsolete. Use one of the previous two functions instead.

§ convertPointsToHomogeneous()

```
void cv::convertPointsToHomogeneous ( InputArray  src,
                                      OutputArray dst
                                    )
```

Python:

```
dst = cv.convertPointsToHomogeneous( src[, dst] )
```

Converts points from Euclidean to homogeneous space.

Parameters

src Input vector of N-dimensional points.

dst Output vector of N+1-dimensional points.

The function converts points from Euclidean to homogeneous space by appending 1's to the tuple of point coordinates. That is, each point (x1, x2, ..., xn) is converted to (x1, x2, ..., xn, 1).

§ correctMatches()

```
void cv::correctMatches ( InputArray  F,
                          InputArray  points1,
                          InputArray  points2,
                          OutputArray newPoints1,
                          OutputArray newPoints2
                        )
```

Python:

```
newPoints1, newPoints2 = cv.correctMatches( F, points1, points2[, newPoints1[, newPoints2]] )
```

Refines coordinates of corresponding points.

Parameters

F 3x3 fundamental matrix.

points1 1xN array containing the first set of points.

points2 1xN array containing the second set of points.

newPoints1 The optimized points1.

newPoints2 The optimized points2.

The function implements the Optimal Triangulation Method (see Multiple View Geometry for details). For each given point correspondence points1[i] <-> points2[i], and a fundamental matrix F, it computes the corrected correspondences newPoints1[i] <-> newPoints2[i] that minimize the geometric error $d(points1[i], newPoints1[i])^2 + d(points2[i], newPoints2[i])^2$ (where $d(a, b)$ is the geometric distance between points a and b) subject to the epipolar constraint $newPoints2^T * F * newPoints1 = 0$.

§ decomposeEssentialMat()

```
void cv::decomposeEssentialMat ( InputArray  E,
                                 OutputArray R1,
                                 OutputArray R2,
                                 OutputArray t
                               )
```

Python:

```
R1, R2, t = cv.decomposeEssentialMat( E[, R1[, R2[, t]]] )
```

Decompose an essential matrix to possible rotations and translation.

Parameters

E The input essential matrix.

R1 One possible rotation matrix.

R2 Another possible rotation matrix.

t One possible translation.

This function decompose an essential matrix E using svd decomposition [77] . Generally 4 possible poses exists for a given E. They are $[R_1, t]$, $[R_1, -t]$, $[R_2, t]$, $[R_2, -t]$. By decomposing E, you can only get the direction of the translation, so the function returns unit t.

§ decomposeHomographyMat()

```
int cv::decomposeHomographyMat ( InputArray          H,
                                 InputArray          K,
                                 OutputArrayOfArrays rotations,
                                 OutputArrayOfArrays translations,
                                 OutputArrayOfArrays normals
                               )
```

Python:

```
retval, rotations, translations, normals = cv.decomposeHomographyMat( H, K[, rotations[, translations[, normals]]] )
```

Decompose a homography matrix to rotation(s), translation(s) and plane normal(s).

Parameters

H	The input homography matrix between two images.
K	The input intrinsic camera calibration matrix.
rotations	Array of rotation matrices.
translations	Array of translation matrices.
normals	Array of plane normal matrices.

This function extracts relative camera motion between two views observing a planar object from the homography H induced by the plane. The intrinsic camera matrix K must also be provided. The function may return up to four mathematical solution sets. At least two of the solutions may further be invalidated if point correspondences are available by applying positive depth constraint (all points must be in front of the camera). The decomposition method is described in detail in **[124]** .

Examples:

samples/cpp/tutorial_code/features2D/Homography/decompose_homography.cpp.

§ decomposeProjectionMatrix()

```
void cv::decomposeProjectionMatrix ( InputArray  projMatrix,
                                     OutputArray cameraMatrix,
                                     OutputArray rotMatrix,
                                     OutputArray transVect,
                                     OutputArray rotMatrixX = noArray(),
                                     OutputArray rotMatrixY = noArray(),
                                     OutputArray rotMatrixZ = noArray(),
                                     OutputArray eulerAngles = noArray()
                                   )
```

Python:

```
cameraMatrix,
rotMatrix,
transVect,
rotMatrixX,     = cv.decomposeProjectionMatrix( projMatrix[, cameraMatrix[, rotMatrix[, transVect[, rotMatrixX[, rotMatrixY[, rotMatrixZ[, eulerAngles]]]]]]] )
rotMatrixY,
rotMatrixZ,
eulerAngles
```

Decomposes a projection matrix into a rotation matrix and a camera matrix.

Parameters

projMatrix	3x4 input projection matrix P.
cameraMatrix	Output 3x3 camera matrix K.
rotMatrix	Output 3x3 external rotation matrix R.
transVect	Output 4x1 translation vector T.
rotMatrixX	Optional 3x3 rotation matrix around x-axis.
rotMatrixY	Optional 3x3 rotation matrix around y-axis.
rotMatrixZ	Optional 3x3 rotation matrix around z-axis.
eulerAngles	Optional three-element vector containing three Euler angles of rotation in degrees.

The function computes a decomposition of a projection matrix into a calibration and a rotation matrix and the position of a camera.

It optionally returns three rotation matrices, one for each axis, and three Euler angles that could be used in OpenGL. Note, there is always more than one sequence of rotations about the three principal axes that results in the same orientation of an object, e.g. see [173] . Returned tree rotation matrices and corresponding three Euler angles are only one of the possible solutions.

The function is based on RQDecomp3x3 .

§ drawChessboardCorners()

```
void cv::drawChessboardCorners ( InputOutputArray image,
                                 Size             patternSize,
                                 InputArray       corners,
                                 bool             patternWasFound
                               )
```

Python:

```
image = cv.drawChessboardCorners( image, patternSize, corners, patternWasFound )
```

Renders the detected chessboard corners.

Parameters

image	Destination image. It must be an 8-bit color image.
patternSize	Number of inner corners per a chessboard row and column (patternSize = cv::Size(points_per_row,points_per_column)).
corners	Array of detected corners, the output of findChessboardCorners.
patternWasFound	Parameter indicating whether the complete board was found or not. The return value of findChessboardCorners should be passed here.

The function draws individual chessboard corners detected either as red circles if the board was not found, or as colored corners connected with lines if the board was found.

Examples:

samples/cpp/tutorial_code/features2D/Homography/pose_from_homography.cpp.

§ estimateAffine2D()

```
cv::Mat cv::estimateAffine2D ( InputArray  from,
                               InputArray  to,
                               OutputArray inliers = noArray(),
                               int         method = RANSAC,
                               double      ransacReprojThreshold = 3,
                               size_t      maxIters = 2000,
                               double      confidence = 0.99,
                               size_t      refineIters = 10
                             )
```

Python:

```
retval, inliers = cv.estimateAffine2D( from, to[, inliers[, method[, ransacReprojThreshold[, maxIters[, confidence[, refineIters]]]]]] )
```

Computes an optimal affine transformation between two 2D point sets.

It computes

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} X \\ Y \end{bmatrix} + \begin{bmatrix} b_1 \\ b_2 \end{bmatrix}$$

Parameters

from	First input 2D point set containing (X, Y).
to	Second input 2D point set containing (x, y).
inliers	Output vector indicating which points are inliers (1-inlier, 0-outlier).
method	Robust method used to compute transformation. The following methods are possible: • **cv::RANSAC** - RANSAC-based robust method • **cv::LMEDS** - Least-Median robust method RANSAC is the default method.
ransacReprojThreshold	Maximum reprojection error in the RANSAC algorithm to consider a point as an inlier. Applies only to RANSAC.
maxIters	The maximum number of robust method iterations.
confidence	Confidence level, between 0 and 1, for the estimated transformation. Anything between 0.95 and 0.99 is usually good enough. Values too close to 1 can slow down the estimation significantly. Values lower than 0.8-0.9 can result in an incorrectly estimated transformation.
refineIters	Maximum number of iterations of refining algorithm (Levenberg-Marquardt). Passing 0 will disable refining, so the output matrix will be output of robust method.

Returns

Output 2D affine transformation matrix 2×3 or empty matrix if transformation could not be estimated. The returned matrix has the following form:

$$\begin{bmatrix} a_{11} & a_{12} & b_1 \\ a_{21} & a_{22} & b_2 \end{bmatrix}$$

The function estimates an optimal 2D affine transformation between two 2D point sets using the selected robust algorithm.

The computed transformation is then refined further (using only inliers) with the Levenberg-Marquardt method to reduce the re-projection error even more.

Note

The RANSAC method can handle practically any ratio of outliers but needs a threshold to distinguish inliers from outliers. The method LMeDS does not need any threshold but it works correctly only when there are more than 50% of inliers.

See also

estimateAffinePartial2D, **getAffineTransform**

§ estimateAffine3D()

```
int cv::estimateAffine3D ( InputArray  src,
                           InputArray  dst,
                           OutputArray out,
                           OutputArray inliers,
                           double      ransacThreshold = 3,
                           double      confidence = 0.99
                         )
```

Python:

```
retval, out, inliers = cv.estimateAffine3D( src, dst[, out[, inliers[, ransacThreshold[, confidence]]]] )
```

Computes an optimal affine transformation between two 3D point sets.

It computes

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix}$$

Parameters

src	First input 3D point set containing (X, Y, Z).
dst	Second input 3D point set containing (x, y, z).
out	Output 3D affine transformation matrix 3×4 of the form $\begin{bmatrix} a_{11} & a_{12} & a_{13} & b_1 \\ a_{21} & a_{22} & a_{23} & b_2 \\ a_{31} & a_{32} & a_{33} & b_3 \end{bmatrix}$
inliers	Output vector indicating which points are inliers (1-inlier, 0-outlier).
ransacThreshold	Maximum reprojection error in the RANSAC algorithm to consider a point as an inlier.
confidence	Confidence level, between 0 and 1, for the estimated transformation. Anything between 0.95 and 0.99 is usually good enough. Values too close to 1 can slow down the estimation significantly. Values lower than 0.8-0.9 can result in an incorrectly estimated transformation.

The function estimates an optimal 3D affine transformation between two 3D point sets using the RANSAC algorithm.

§ estimateAffinePartial2D()

```
cv::Mat cv::estimateAffinePartial2D ( InputArray  from,
                                      InputArray  to,
                                      OutputArray inliers = noArray(),
                                      int         method = RANSAC,
                                      double      ransacReprojThreshold = 3,
                                      size_t      maxIters = 2000,
                                      double      confidence = 0.99,
                                      size_t      refineIters = 10
                                    )
```

Python:

```
retval, inliers = cv.estimateAffinePartial2D( from, to[, inliers[, method[, ransacReprojThreshold[, maxIters[, confidence[, refineIters]]]]]] )
```

Computes an optimal limited affine transformation with 4 degrees of freedom between two 2D point sets.

Parameters

from	First input 2D point set.
to	Second input 2D point set.
inliers	Output vector indicating which points are inliers.
method	Robust method used to compute transformation. The following methods are possible: - **cv::RANSAC** - RANSAC-based robust method - **cv::LMEDS** - Least-Median robust method RANSAC is the default method.
ransacReprojThreshold	Maximum reprojection error in the RANSAC algorithm to consider a point as an inlier. Applies only to RANSAC.
maxIters	The maximum number of robust method iterations.
confidence	Confidence level, between 0 and 1, for the estimated transformation. Anything between 0.95 and 0.99 is usually good enough. Values too close to 1 can slow down the estimation significantly. Values lower than 0.8-0.9 can result in an incorrectly estimated transformation.
refineIters	Maximum number of iterations of refining algorithm (Levenberg-Marquardt). Passing 0 will disable refining, so the output matrix will be output of robust method.

Returns

Output 2D affine transformation (4 degrees of freedom) matrix 2×3 or empty matrix if transformation could not be estimated.

The function estimates an optimal 2D affine transformation with 4 degrees of freedom limited to combinations of translation, rotation, and uniform scaling. Uses the selected algorithm for robust estimation.

The computed transformation is then refined further (using only inliers) with the Levenberg-Marquardt method to reduce the re-projection error even more.

Estimated transformation matrix is:

$$\begin{bmatrix} \cos(\theta) \cdot s & -\sin(\theta) \cdot s & t_x \\ \sin(\theta) \cdot s & \cos(\theta) \cdot s & t_y \end{bmatrix}$$

Where θ is the rotation angle, s the scaling factor and t_x, t_y are translations in x, y axes respectively.

Note

The RANSAC method can handle practically any ratio of outliers but need a threshold to distinguish inliers from outliers. The method LMeDS does not need any threshold but it works correctly only when there are more than 50% of inliers.

See also

estimateAffine2D, getAffineTransform

§ filterHomographyDecompByVisibleRefpoints()

```
void cv::filterHomographyDecompByVisibleRefpoints ( InputArrayOfArrays rotations,
                                                    InputArrayOfArrays normals,
                                                    InputArray beforePoints,
                                                    InputArray afterPoints,
                                                    OutputArray possibleSolutions,
                                                    InputArray pointsMask = noArray()
                                                  )
```

Python:

```
possibleSolutions = cv.filterHomographyDecompByVisibleRefpoints( rotations, normals, beforePoints, afterPoints[, possibleSolutions[, pointsMask]] )
```

Filters homography decompositions based on additional information.

Parameters

rotations	Vector of rotation matrices.
normals	Vector of plane normal matrices.
beforePoints	Vector of (rectified) visible reference points before the homography is applied
afterPoints	Vector of (rectified) visible reference points after the homography is applied
possibleSolutions	Vector of int indices representing the viable solution set after filtering
pointsMask	optional Mat/Vector of 8u type representing the mask for the inliers as given by the findHomography function

This function is intended to filter the output of the decomposeHomographyMat based on additional information as described in [124] . The summary of the method: the decomposeHomographyMat function returns 2 unique solutions and their "opposites" for a total of 4 solutions. If we have access to the sets of points visible in the camera frame before and after the homography transformation is applied, we can determine which are the true potential solutions and which are the opposites by verifying which homographies are consistent with all visible reference points being in front of the camera. The inputs are left unchanged; the filtered solution set is returned as indices into the existing one.

§ filterSpeckles()

```
void cv::filterSpeckles ( InputOutputArray img,
                          double newVal,
                          int maxSpeckleSize,
                          double maxDiff,
                          InputOutputArray buf = noArray()
                        )
```

Python:

```
img, buf = cv.filterSpeckles( img, newVal, maxSpeckleSize, maxDiff[, buf] )
```

Filters off small noise blobs (speckles) in the disparity map.

Parameters

img	The input 16-bit signed disparity image
newVal	The disparity value used to paint-off the speckles
maxSpeckleSize	The maximum speckle size to consider it a speckle. Larger blobs are not affected by the algorithm
maxDiff	Maximum difference between neighbor disparity pixels to put them into the same blob. Note that since **StereoBM**, **StereoSGBM** and may be other algorithms return a fixed-point disparity map, where disparity values are multiplied by 16, this scale factor should be taken into account when specifying this parameter value.
buf	The optional temporary buffer to avoid memory allocation within the function.

§ find4QuadCornerSubpix()

```
bool cv::find4QuadCornerSubpix ( InputArray img,
                                 InputOutputArray corners,
                                 Size region_size
                               )
```

finds subpixel-accurate positions of the chessboard corners

§ findChessboardCorners()

```
bool cv::findChessboardCorners ( InputArray  image,
                                 Size        patternSize,
                                 OutputArray corners,
                                 int         flags = CALIB_CB_ADAPTIVE_THRESH+CALIB_CB_NORMALIZE_IMAGE
                               )
```

Python:

```
retval, corners = cv.findChessboardCorners( image, patternSize[, corners[, flags]] )
```

Finds the positions of internal corners of the chessboard.

Parameters

image	Source chessboard view. It must be an 8-bit grayscale or color image.
patternSize	Number of inner corners per a chessboard row and column (patternSize = cvSize(points_per_row,points_per_colum) = cvSize(columns,rows)).
corners	Output array of detected corners.
flags	Various operation flags that can be zero or a combination of the following values:

- **CALIB_CB_ADAPTIVE_THRESH** Use adaptive thresholding to convert the image to black and white, rather than a fixed threshold level (computed from the average image brightness).
- **CALIB_CB_NORMALIZE_IMAGE** Normalize the image gamma with equalizeHist before applying fixed or adaptive thresholding.
- **CALIB_CB_FILTER_QUADS** Use additional criteria (like contour area, perimeter, square-like shape) to filter out false quads extracted at the contour retrieval stage.
- **CALIB_CB_FAST_CHECK** Run a fast check on the image that looks for chessboard corners, and shortcut the call if none is found. This can drastically speed up the call in the degenerate condition when no chessboard is observed.

The function attempts to determine whether the input image is a view of the chessboard pattern and locate the internal chessboard corners. The function returns a non-zero value if all of the corners are found and they are placed in a certain order (row by row, left to right in every row). Otherwise, if the function fails to find all the corners or reorder them, it returns 0. For example, a regular chessboard has 8 x 8 squares and 7 x 7 internal corners, that is, points where the black squares touch each other. The detected coordinates are approximate, and to determine their positions more accurately, the function calls cornerSubPix. You also may use the function cornerSubPix with different parameters if returned coordinates are not accurate enough.

Sample usage of detecting and drawing chessboard corners: :

```
Size patternsize(8,6); //interior number of corners
Mat gray = ....; //source image
vector<Point2f> corners; //this will be filled by the detected corners

//CALIB_CB_FAST_CHECK saves a lot of time on images
//that do not contain any chessboard corners
bool patternfound = findChessboardCorners(gray, patternsize, corners,
        CALIB_CB_ADAPTIVE_THRESH + CALIB_CB_NORMALIZE_IMAGE
        + CALIB_CB_FAST_CHECK);

if(patternfound)
  cornerSubPix(gray, corners, Size(11, 11), Size(-1, -1),
    TermCriteria(CV_TERMCRIT_EPS + CV_TERMCRIT_ITER, 30, 0.1));

drawChessboardCorners(img, patternsize, Mat(corners), patternfound);
```

Note

The function requires white space (like a square-thick border, the wider the better) around the board to make the detection more robust in various environments. Otherwise, if there is no border and the background is dark, the outer black squares cannot be segmented properly and so the square grouping and ordering algorithm fails.

Examples:

samples/cpp/tutorial_code/features2D/Homography/decompose_homography.cpp,
samples/cpp/tutorial_code/features2D/Homography/homography_from_camera_displacement.cpp, and
samples/cpp/tutorial_code/features2D/Homography/pose_from_homography.cpp.

§ findCirclesGrid() [1/2]

```
bool cv::findCirclesGrid ( InputArray                image,
                           Size                      patternSize,
                           OutputArray               centers,
                           int                       flags,
                           const Ptr< FeatureDetector > &  blobDetector,
                           CirclesGridFinderParameters  parameters
                         )
```

Python:

```
retval, centers = cv.findCirclesGrid( image, patternSize, flags, blobDetector, parameters[, centers] )
retval, centers = cv.findCirclesGrid( image, patternSize[, centers[, flags[, blobDetector]]] )
```

Finds centers in the grid of circles.

Parameters

image	grid view of input circles; it must be an 8-bit grayscale or color image.
patternSize	number of circles per row and column (patternSize = Size(points_per_row, points_per_colum)).
centers	output array of detected centers.
flags	various operation flags that can be one of the following values: • **CALIB_CB_SYMMETRIC_GRID** uses symmetric pattern of circles. • **CALIB_CB_ASYMMETRIC_GRID** uses asymmetric pattern of circles. • **CALIB_CB_CLUSTERING** uses a special algorithm for grid detection. It is more robust to perspective distortions but much more sensitive to background clutter.
blobDetector	feature detector that finds blobs like dark circles on light background.
parameters	struct for finding circles in a grid pattern.

The function attempts to determine whether the input image contains a grid of circles. If it is, the function locates centers of the circles. The function returns a non-zero value if all of the centers have been found and they have been placed in a certain order (row by row, left to right in every row). Otherwise, if the function fails to find all the corners or reorder them, it returns 0.

Sample usage of detecting and drawing the centers of circles: :

```
Size patternsize(7,7); //number of centers
Mat gray = ....; //source image
vector<Point2f> centers; //this will be filled by the detected centers

bool patternfound = findCirclesGrid(gray, patternsize, centers);

drawChessboardCorners(img, patternsize, Mat(centers), patternfound);
```

Note

The function requires white space (like a square-thick border, the wider the better) around the board to make the detection more robust in various environments.

§ findCirclesGrid() [2/2]

```
bool cv::findCirclesGrid ( InputArray                image,
                           Size                      patternSize,
                           OutputArray               centers,
                           int                       flags = CALIB_CB_SYMMETRIC_GRID,
                           const Ptr< FeatureDetector > &  blobDetector = SimpleBlobDetector::create()
                         )
```

Python:

```
retval, centers = cv.findCirclesGrid( image, patternSize, flags, blobDetector, parameters[, centers] )
retval, centers = cv.findCirclesGrid( image, patternSize[, centers[, flags[, blobDetector]]] )
```

This is an overloaded member function, provided for convenience. It differs from the above function only in what argument(s) it accepts.

§ findCirclesGrid2()

```
bool cv::findCirclesGrid2 ( InputArray                image,
                            Size                      patternSize,
                            OutputArray               centers,
                            int                       flags,
                            const Ptr< FeatureDetector > &  blobDetector,
                            CirclesGridFinderParameters2  parameters
                          )
```

Python:

```
retval, centers = cv.findCirclesGrid2( image, patternSize, flags, blobDetector, parameters[, centers] )
```

This is an overloaded member function, provided for convenience. It differs from the above function only in what argument(s) it accepts.

§ findEssentialMat() [1/2]

```
Mat cv::findEssentialMat ( InputArray  points1,
                           InputArray  points2,
                           InputArray  cameraMatrix,
                           int         method = RANSAC,
                           double      prob = 0.999,
                           double      threshold = 1.0,
                           OutputArray mask = noArray()
                         )
```

Python:

```
retval, mask = cv.findEssentialMat( points1, points2, cameraMatrix[, method[, prob[, threshold[, mask]]]] )
retval, mask = cv.findEssentialMat( points1, points2[, focal[, pp[, method[, prob[, threshold[, mask]]]]]] )
```

Calculates an essential matrix from the corresponding points in two images.

Parameters

points1	Array of N (N >= 5) 2D points from the first image. The point coordinates should be floating-point (single or double precision).
points2	Array of the second image points of the same size and format as points1 .
cameraMatrix	Camera matrix $K = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}$. Note that this function assumes that points1 and points2 are feature points from cameras with the same camera matrix.
method	Method for computing an essential matrix. • **RANSAC** for the RANSAC algorithm. • **LMEDS** for the LMedS algorithm.
prob	Parameter used for the RANSAC or LMedS methods only. It specifies a desirable level of confidence (probability) that the estimated matrix is correct.
threshold	Parameter used for RANSAC. It is the maximum distance from a point to an epipolar line in pixels, beyond which the point is considered an outlier and is not used for computing the final fundamental matrix. It can be set to something like 1-3, depending on the accuracy of the point localization, image resolution, and the image noise.
mask	Output array of N elements, every element of which is set to 0 for outliers and to 1 for the other points. The array is computed only in the RANSAC and LMedS methods.

This function estimates essential matrix based on the five-point algorithm solver in [144] . [174] is also a related. The epipolar geometry is described by the following equation:

$$[p_2; 1]^T K^{-T} E K^{-1} [p_1; 1] = 0$$

where E is an essential matrix, p_1 and p_2 are corresponding points in the first and the second images, respectively. The result of this function may be passed further to decomposeEssentialMat or recoverPose to recover the relative pose between cameras.

§ findEssentialMat() [2/2]

```
Mat cv::findEssentialMat ( InputArray  points1,
                           InputArray  points2,
                           double      focal = 1.0,
                           Point2d     pp = Point2d(0, 0),
                           int         method = RANSAC,
                           double      prob = 0.999,
                           double      threshold = 1.0,
                           OutputArray mask = noArray()
                         )
```

Python:

```
retval, mask = cv.findEssentialMat( points1, points2, cameraMatrix[, method[, prob[, threshold[, mask]]]] )
retval, mask = cv.findEssentialMat( points1, points2[, focal[, pp[, method[, prob[, threshold[, mask]]]]]] )
```

This is an overloaded member function, provided for convenience. It differs from the above function only in what argument(s) it accepts.

Parameters

points1	Array of N (N >= 5) 2D points from the first image. The point coordinates should be floating-point (single or double precision).
points2	Array of the second image points of the same size and format as points1 .
focal	focal length of the camera. Note that this function assumes that points1 and points2 are feature points from cameras with same focal length and principal point.
pp	principal point of the camera.
method	Method for computing a fundamental matrix. • **RANSAC** for the RANSAC algorithm. • **LMEDS** for the LMedS algorithm.
threshold	Parameter used for RANSAC. It is the maximum distance from a point to an epipolar line in pixels, beyond which the point is considered an outlier and is not used for computing the final fundamental matrix. It can be set to something like 1-3, depending on the accuracy of the point localization, image resolution, and the image noise.
prob	Parameter used for the RANSAC or LMedS methods only. It specifies a desirable level of confidence (probability) that the estimated matrix is correct.
mask	Output array of N elements, every element of which is set to 0 for outliers and to 1 for the other points. The array is computed only in the RANSAC and LMedS methods.

This function differs from the one above that it computes camera matrix from focal length and principal point:

$$K = \begin{bmatrix} f & 0 & x_{pp} \\ 0 & f & y_{pp} \\ 0 & 0 & 1 \end{bmatrix}$$

§ findFundamentalMat() [1/2]

```
Mat cv::findFundamentalMat ( InputArray  points1,
                             InputArray  points2,
                             int         method = FM_RANSAC,
                             double      ransacReprojThreshold = 3.,
                             double      confidence = 0.99,
                             OutputArray mask = noArray()
                           )
```

Python:

```
retval, mask = cv.findFundamentalMat( points1, points2[, method[, ransacReprojThreshold[, confidence[, mask]]]] )
```

Calculates a fundamental matrix from the corresponding points in two images.

Parameters

points1	Array of N points from the first image. The point coordinates should be floating-point (single or double precision).
points2	Array of the second image points of the same size and format as points1 .
method	Method for computing a fundamental matrix. • **CV_FM_7POINT** for a 7-point algorithm. $N = 7$ • **CV_FM_8POINT** for an 8-point algorithm. $N \geq 8$ • **CV_FM_RANSAC** for the RANSAC algorithm. $N \geq 8$ • **CV_FM_LMEDS** for the LMedS algorithm. $N \geq 8$
ransacReprojThreshold	Parameter used only for RANSAC. It is the maximum distance from a point to an epipolar line in pixels, beyond which the point is considered an outlier and is not used for computing the final fundamental matrix. It can be set to something like 1-3, depending on the accuracy of the point localization, image resolution, and the image noise.
confidence	Parameter used for the RANSAC and LMedS methods only. It specifies a desirable level of confidence (probability) that the estimated matrix is correct.
mask	The epipolar geometry is described by the following equation:

$$[p_2; 1]^T F [p_1; 1] = 0$$

where F is a fundamental matrix, p_1 and p_2 are corresponding points in the first and the second images, respectively.

The function calculates the fundamental matrix using one of four methods listed above and returns the found fundamental matrix. Normally just one matrix is found. But in case of the 7-point algorithm, the function may return up to 3 solutions (9×3 matrix that stores all 3 matrices sequentially).

The calculated fundamental matrix may be passed further to computeCorrespondEpilines that finds the epipolar lines corresponding to the specified points. It can also be passed to stereoRectifyUncalibrated to compute the rectification transformation. :

```
// Example. Estimation of fundamental matrix using the RANSAC algorithm
int point_count = 100;
vector<Point2f> points1(point_count);
vector<Point2f> points2(point_count);

// initialize the points here ...
for( int i = 0; i < point_count; i++ )
{
    points1[i] = ...;
    points2[i] = ...;
}

Mat fundamental_matrix =
 findFundamentalMat(points1, points2, FM_RANSAC, 3, 0.99);
```

§ findFundamentalMat() [2/2]

```
Mat cv::findFundamentalMat ( InputArray  points1,
                             InputArray  points2,
                             OutputArray mask,
                             int         method = FM_RANSAC,
                             double      ransacReprojThreshold = 3.,
                             double      confidence = 0.99
                           )
```

Python:

```
retval, mask = cv.findFundamentalMat( points1, points2[, method[, ransacReprojThreshold[, confidence[, mask]]]] )
```

This is an overloaded member function, provided for convenience. It differs from the above function only in what argument(s) it accepts.

§ findHomography() [1/2]

```
Mat cv::findHomography ( InputArray  srcPoints,
                         InputArray  dstPoints,
                         int         method = 0,
                                     ransacReprojThreshold =
                         double      3,
                         OutputArray mask = noArray(),
                         const int   maxIters = 2000,
                         const double confidence = 0.995
                       )
```

Python:

```
retval, mask = cv.findHomography( srcPoints, dstPoints[, method[, ransacReprojThreshold[, mask[, maxIters[, confidence]]]]] )
```

Finds a perspective transformation between two planes.

Parameters

srcPoints	Coordinates of the points in the original plane, a matrix of the type CV_32FC2 or vector<Point2f> .
dstPoints	Coordinates of the points in the target plane, a matrix of the type CV_32FC2 or a vector<Point2f> .
method	Method used to compute a homography matrix. The following methods are possible: • **0** - a regular method using all the points, i.e., the least squares method • **RANSAC** - RANSAC-based robust method • **LMEDS** - Least-Median robust method • **RHO** - PROSAC-based robust method
ransacReprojThreshold	Maximum allowed reprojection error to treat a point pair as an inlier (used in the RANSAC and RHO methods only). That is, if $\|\texttt{dstPoints}_i - \texttt{convertPointsHomogeneous}(\texttt{H} * \texttt{srcPoints}_i)\|_2 > \texttt{ransacReprojThreshold}$ then the point i is considered as an outlier. If srcPoints and dstPoints are measured in pixels, it usually makes sense to set this parameter somewhere in the range of 1 to 10.
mask	Optional output mask set by a robust method (RANSAC or LMEDS). Note that the input mask values are ignored.
maxIters	The maximum number of RANSAC iterations.
confidence	Confidence level, between 0 and 1.

The function finds and returns the perspective transformation H between the source and the destination planes:

$$s_i \begin{bmatrix} x'_i \\ y'_i \\ 1 \end{bmatrix} \sim H \begin{bmatrix} x_i \\ y_i \\ 1 \end{bmatrix}$$

so that the back-projection error

$$\sum_i \left(x'_i - \frac{h_{11} x_i + h_{12} y_i + h_{13}}{h_{31} x_i + h_{32} y_i + h_{33}} \right)^2 + \left(y'_i - \frac{h_{21} x_i + h_{22} y_i + h_{23}}{h_{31} x_i + h_{32} y_i + h_{33}} \right)^2$$

is minimized. If the parameter method is set to the default value 0, the function uses all the point pairs to compute an initial homography estimate with a simple least-squares scheme.

However, if not all of the point pairs ($srcPoints_i$, $dstPoints_i$) fit the rigid perspective transformation (that is, there are some outliers), this initial estimate will be poor. In this case, you can use one of the three robust methods. The methods RANSAC, LMeDS and RHO try many different random subsets of the corresponding point pairs (of four pairs each, collinear pairs are discarded), estimate the homography matrix using this subset and a simple least-squares algorithm, and then compute the quality/goodness of the computed homography (which is the number of inliers for RANSAC or the least median re-projection error for LMeDS). The best subset is then used to produce the initial estimate of the homography matrix and the mask of inliers/outliers.

Regardless of the method, robust or not, the computed homography matrix is refined further (using inliers only in case of a robust method) with the Levenberg-Marquardt method to reduce the re-projection error even more.

The methods RANSAC and RHO can handle practically any ratio of outliers but need a threshold to distinguish inliers from outliers. The method LMeDS does not need any threshold but it works correctly only when there are more than 50% of inliers. Finally, if there are no outliers and the noise is rather small, use the default method (method=0).

The function is used to find initial intrinsic and extrinsic matrices. Homography matrix is determined up to a scale. Thus, it is normalized so that $h_{33} = 1$. Note that whenever an H matrix cannot be estimated, an empty one will be returned.

See also

getAffineTransform, estimateAffine2D, estimateAffinePartial2D, getPerspectiveTransform, warpPerspective, perspectiveTransform

Examples:

samples/cpp/tutorial_code/features2D/Homography/decompose_homography.cpp,
samples/cpp/tutorial_code/features2D/Homography/homography_from_camera_displacement.cpp,

samples/cpp/tutorial_code/features2D/Homography/pose_from_homography.cpp, and samples/cpp/warpPerspective_demo.cpp.

§ findHomography() [2/2]

```
Mat cv::findHomography ( InputArray  srcPoints,
                         InputArray  dstPoints,
                         OutputArray mask,
                         int         method = 0,
                         double      ransacReprojThreshold = 3
                       )
```

Python:

```
retval, mask = cv.findHomography( srcPoints, dstPoints[, method[, ransacReprojThreshold[, mask[, maxIters[, confidence]]]]] )
```

This is an overloaded member function, provided for convenience. It differs from the above function only in what argument(s) it accepts.

§ getOptimalNewCameraMatrix()

```
Mat cv::getOptimalNewCameraMatrix ( InputArray  cameraMatrix,
                                    InputArray  distCoeffs,
                                    Size        imageSize,
                                    double      alpha,
                                    Size        newImgSize = Size(),
                                    Rect *      validPixROI = 0,
                                    bool        centerPrincipalPoint = false
                                  )
```

Python:

```
retval, validPixROI = cv.getOptimalNewCameraMatrix( cameraMatrix, distCoeffs, imageSize, alpha[, newImgSize[, centerPrincipalPoint]] )
```

Returns the new camera matrix based on the free scaling parameter.

Parameters

cameraMatrix	Input camera matrix.
distCoeffs	Input vector of distortion coefficients $(k_1, k_2, p_1, p_2[, k_3[, k_4, k_5, k_6[, s_1, s_2, s_3, s_4[, \tau_x, \tau_y]]]])$ of 4, 5, 8, 12 or 14 elements. If the vector is NULL/empty, the zero distortion coefficients are assumed.
imageSize	Original image size.
alpha	Free scaling parameter between 0 (when all the pixels in the undistorted image are valid) and 1 (when all the source image pixels are retained in the undistorted image). See stereoRectify for details.
newImgSize	Image size after rectification. By default, it is set to imageSize .
validPixROI	Optional output rectangle that outlines all-good-pixels region in the undistorted image. See roi1, roi2 description in stereoRectify .
centerPrincipalPoint	Optional flag that indicates whether in the new camera matrix the principal point should be at the image center or not. By default, the principal point is chosen to best fit a subset of the source image (determined by alpha) to the corrected image.

Returns

new_camera_matrix Output new camera matrix.

The function computes and returns the optimal new camera matrix based on the free scaling parameter. By varying this parameter, you may retrieve only sensible pixels alpha=0 , keep all the original image pixels if there is valuable information in the corners alpha=1 , or get something in between. When alpha>0 , the undistorted result is likely to have some black pixels corresponding to "virtual" pixels outside of the captured distorted image. The original camera matrix, distortion coefficients, the computed new camera matrix, and newImageSize should be passed to initUndistortRectifyMap to produce the maps for remap .

§ getValidDisparityROI()

```
Rect cv::getValidDisparityROI ( Rect roi1,
                                Rect roi2,
                                int minDisparity,
                                int numberOfDisparities,
                                int SADWindowSize
                              )
```

Python:

```
retval = cv.getValidDisparityROI( roi1, roi2, minDisparity, numberOfDisparities, SADWindowSize )
```

computes valid disparity ROI from the valid ROIs of the rectified images (that are returned by **cv::stereoRectify()**)

§ initCameraMatrix2D()

```
Mat cv::initCameraMatrix2D ( InputArrayOfArrays objectPoints,
                             InputArrayOfArrays imagePoints,
                             Size imageSize,
                             double aspectRatio = 1.0
                           )
```

Python:

```
retval = cv.initCameraMatrix2D( objectPoints, imagePoints, imageSize[, aspectRatio] )
```

Finds an initial camera matrix from 3D-2D point correspondences.

Parameters

objectPoints	Vector of vectors of the calibration pattern points in the calibration pattern coordinate space. In the old interface all the per-view vectors are concatenated. See calibrateCamera for details.
imagePoints	Vector of vectors of the projections of the calibration pattern points. In the old interface all the per-view vectors are concatenated.
imageSize	Image size in pixels used to initialize the principal point.
aspectRatio	If it is zero or negative, both f_x and f_y are estimated independently. Otherwise, $f_x = f_y * \texttt{aspectRatio}$.

The function estimates and returns an initial camera matrix for the camera calibration process. Currently, the function only supports planar calibration patterns, which are patterns where each object point has z-coordinate =0.

§ matMulDeriv()

```
void cv::matMulDeriv ( InputArray A,
                       InputArray B,
                       OutputArray dABdA,
                       OutputArray dABdB
                     )
```

Python:

```
dABdA, dABdB = cv.matMulDeriv( A, B[, dABdA[, dABdB]] )
```

Computes partial derivatives of the matrix product for each multiplied matrix.

Parameters

A	First multiplied matrix.
B	Second multiplied matrix.
dABdA	First output derivative matrix d(A*B)/dA of size $\texttt{A.rows*B.cols} \times A.rows * A.cols$.
dABdB	Second output derivative matrix d(A*B)/dB of size $\texttt{A.rows*B.cols} \times B.rows * B.cols$.

The function computes partial derivatives of the elements of the matrix product $A * B$ with regard to the elements of each of the two input matrices. The function is used to compute the Jacobian matrices in stereoCalibrate but can also be used in any other similar optimization function.

§ projectPoints()

```
void cv::projectPoints ( InputArray  objectPoints,
                         InputArray  rvec,
                         InputArray  tvec,
                         InputArray  cameraMatrix,
                         InputArray  distCoeffs,
                         OutputArray imagePoints,
                         jacobian =
                         OutputArray noArray(),
                         double      aspectRatio = 0
                       )
```

Python:

```
imagePoints, jacobian = cv.projectPoints( objectPoints, rvec, tvec, cameraMatrix, distCoeffs[, imagePoints[, jacobian[, aspectRatio]]] )
```

Projects 3D points to an image plane.

Parameters

objectPoints	Array of object points, 3xN/Nx3 1-channel or 1xN/Nx1 3-channel (or vector<Point3f>), where N is the number of points in the view.
rvec	Rotation vector. See Rodrigues for details.
tvec	Translation vector.
cameraMatrix	Camera matrix $A = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}$.
distCoeffs	Input vector of distortion coefficients $(k_1, k_2, p_1, p_2[, k_3[, k_4, k_5, k_6[, s_1, s_2, s_3, s_4[, \tau_x, \tau_y]]]])$ of 4, 5, 8, 12 or 14 elements. If the vector is empty, the zero distortion coefficients are assumed.
imagePoints	Output array of image points, 2xN/Nx2 1-channel or 1xN/Nx1 2-channel, or vector<Point2f> .
jacobian	Optional output 2Nx(10+<numDistCoeffs>) jacobian matrix of derivatives of image points with respect to components of the rotation vector, translation vector, focal lengths, coordinates of the principal point and the distortion coefficients. In the old interface different components of the jacobian are returned via different output parameters.
aspectRatio	Optional "fixed aspect ratio" parameter. If the parameter is not 0, the function assumes that the aspect ratio (*fx/fy*) is fixed and correspondingly adjusts the jacobian matrix.

The function computes projections of 3D points to the image plane given intrinsic and extrinsic camera parameters. Optionally, the function computes Jacobians - matrices of partial derivatives of image points coordinates (as functions of all the input parameters) with respect to the particular parameters, intrinsic and/or extrinsic. The Jacobians are used during the global optimization in calibrateCamera, solvePnP, and stereoCalibrate . The function itself can also be used to compute a re-projection error given the current intrinsic and extrinsic parameters.

Note

By setting rvec=tvec=(0,0,0) or by setting cameraMatrix to a 3x3 identity matrix, or by passing zero distortion coefficients, you can get various useful partial cases of the function. This means that you can compute the distorted coordinates for a sparse set of points or apply a perspective transformation (and also compute the derivatives) in the ideal zero-distortion setup.

§ recoverPose() [1/3]

```
int cv::recoverPose ( InputArray      E,
                      InputArray      points1,
                      InputArray      points2,
                      InputArray      cameraMatrix,
                      OutputArray     R,
                      OutputArray     t,
                      InputOutputArray mask = noArray()
                    )
```

Python:

```
retval, R, t, mask                          = cv.recoverPose( E, points1, points2, cameraMatrix[, R[, t[, mask]]] )
retval, R, t, mask                          = cv.recoverPose( E, points1, points2[, R[, t[, focal[, pp[, mask]]]]] )
retval, R, t, mask, triangulatedPoints = cv.recoverPose( E, points1, points2, cameraMatrix, distanceThresh[, R[, t[, mask[, triangulatedPoints]]]] )
```

Recover relative camera rotation and translation from an estimated essential matrix and the corresponding points in two images, using cheirality check. Returns the number of inliers which pass the check.

Parameters

E	The input essential matrix.
points1	Array of N 2D points from the first image. The point coordinates should be floating-point (single or double precision).
points2	Array of the second image points of the same size and format as points1 .
cameraMatrix	Camera matrix $K = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}$. Note that this function assumes that points1 and points2 are feature points from cameras with the same camera matrix.
R	Recovered relative rotation.
t	Recovered relative translation.
mask	Input/output mask for inliers in points1 and points2. : If it is not empty, then it marks inliers in points1 and points2 for then given essential matrix E. Only these inliers will be used to recover pose. In the output mask only inliers which pass the cheirality check. This function decomposes an essential matrix using decomposeEssentialMat and then verifies possible pose hypotheses by doing cheirality check. The cheirality check basically means that the triangulated 3D points should have positive depth. Some details can be found in **[144]** .

This function can be used to process output E and mask from findEssentialMat. In this scenario, points1 and points2 are the same input for findEssentialMat. :

```
// Example. Estimation of fundamental matrix using the RANSAC algorithm
int point_count = 100;
vector<Point2f> points1(point_count);
vector<Point2f> points2(point_count);

// initialize the points here ...
for( int i = 0; i < point_count; i++ )
{
    points1[i] = ...;
    points2[i] = ...;
}

// cametra matrix with both focal lengths = 1, and principal point = (0, 0)
Mat cameraMatrix = Mat::eye(3, 3, CV_64F);

Mat E, R, t, mask;

E = findEssentialMat(points1, points2, cameraMatrix, RANSAC, 0.999, 1.0, mask);
recoverPose(E, points1, points2, cameraMatrix, R, t, mask);
```

§ recoverPose() [2/3]

```
int cv::recoverPose ( InputArray          E,
                      InputArray          points1,
                      InputArray          points2,
                      OutputArray         R,
                      OutputArray         t,
                      double              focal = 1.0,
                      Point2d             pp = Point2d(0, 0),
                      InputOutputArray    mask = noArray()
                    )
```

Python:

```
retval, R, t, mask                      = cv.recoverPose( E, points1, points2, cameraMatrix[, R[, t[, mask]]] )
retval, R, t, mask                      = cv.recoverPose( E, points1, points2[, R[, t[, focal[, pp[, mask]]]]] )
retval, R, t, mask, triangulatedPoints = cv.recoverPose( E, points1, points2, cameraMatrix, distanceThresh[, R[, t[, mask[, triangulatedPoints]]]] )
```

This is an overloaded member function, provided for convenience. It differs from the above function only in what argument(s) it accepts.

Parameters

E	The input essential matrix.
points1	Array of N 2D points from the first image. The point coordinates should be floating-point (single or double precision).
points2	Array of the second image points of the same size and format as points1 .
R	Recovered relative rotation.
t	Recovered relative translation.
focal	Focal length of the camera. Note that this function assumes that points1 and points2 are feature points from cameras with same focal length and principal point.
pp	principal point of the camera.
mask	Input/output mask for inliers in points1 and points2. : If it is not empty, then it marks inliers in points1 and points2 for then given essential matrix E. Only these inliers will be used to recover pose. In the output mask only inliers which pass the cheirality check.

This function differs from the one above that it computes camera matrix from focal length and principal point:

$$K = \begin{bmatrix} f & 0 & x_{pp} \\ 0 & f & y_{pp} \\ 0 & 0 & 1 \end{bmatrix}$$

§ recoverPose() [3/3]

```
int cv::recoverPose ( InputArray      E,
                      InputArray      points1,
                      InputArray      points2,
                      InputArray      cameraMatrix,
                      OutputArray     R,
                      OutputArray     t,
                      double          distanceThresh,
                      InputOutputArray mask = noArray(),
                      OutputArray     triangulatedPoints = noArray()
                    )
```

Python:

```
retval, R, t, mask                      = cv.recoverPose( E, points1, points2, cameraMatrix[, R[, t[, mask]]] )
retval, R, t, mask                      = cv.recoverPose( E, points1, points2[, R[, t[, focal[, pp[, mask]]]]] )
retval, R, t, mask, triangulatedPoints = cv.recoverPose( E, points1, points2, cameraMatrix, distanceThresh[, R[, t[, mask[, triangulatedPoints]]]] )
```

This is an overloaded member function, provided for convenience. It differs from the above function only in what argument(s) it accepts.

Parameters

E	The input essential matrix.
points1	Array of N 2D points from the first image. The point coordinates should be floating-point (single or double precision).
points2	Array of the second image points of the same size and format as points1.
cameraMatrix	Camera matrix $K = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}$. Note that this function assumes that points1 and points2 are feature points from cameras with the same camera matrix.
R	Recovered relative rotation.
t	Recovered relative translation.
distanceThresh	threshold distance which is used to filter out far away points (i.e. infinite points).
mask	Input/output mask for inliers in points1 and points2. : If it is not empty, then it marks inliers in points1 and points2 for then given essential matrix E. Only these inliers will be used to recover pose. In the output mask only inliers which pass the cheirality check.
triangulatedPoints	3d points which were reconstructed by triangulation.

§ rectify3Collinear()

```
float cv::rectify3Collinear ( InputArray          cameraMatrix1,
                              InputArray          distCoeffs1,
                              InputArray          cameraMatrix2,
                              InputArray          distCoeffs2,
                              InputArray          cameraMatrix3,
                              InputArray          distCoeffs3,
                              InputArrayOfArrays  imgpt1,
                              InputArrayOfArrays  imgpt3,
                              Size                imageSize,
                              InputArray          R12,
                              InputArray          T12,
                              InputArray          R13,
                              InputArray          T13,
                              OutputArray         R1,
                              OutputArray         R2,
                              OutputArray         R3,
                              OutputArray         P1,
                              OutputArray         P2,
                              OutputArray         P3,
                              OutputArray         Q,
                              double              alpha,
                              Size                newImgSize,
                              Rect *              roi1,
                              Rect *              roi2,
                              int                 flags
                            )
```

Python:

```
retval,
R1,
R2,
R3,
P1,
P2,
P3,
Q,
roi1,
roi2
    = cv.rectify3Collinear( cameraMatrix1, distCoeffs1, cameraMatrix2, distCoeffs2, cameraMatrix3, distCoeffs3, imgpt1, imgpt3, imageSize, R12, T12, R13, T13,
```

computes the rectification transformations for 3-head camera, where all the heads are on the same line.

§ reprojectImageTo3D()

```
void cv::reprojectImageTo3D ( InputArray  disparity,
                              OutputArray _3dImage,
                              InputArray  Q,
                              bool        handleMissingValues = false,
                              int         ddepth = -1
                            )
```

Python:

```
_3dImage = cv.reprojectImageTo3D( disparity, Q[, _3dImage[, handleMissingValues[, ddepth]]] )
```

Reprojects a disparity image to 3D space.

Parameters

disparity	Input single-channel 8-bit unsigned, 16-bit signed, 32-bit signed or 32-bit floating-point disparity image. If 16-bit signed format is used, the values are assumed to have no fractional bits.
_3dImage	Output 3-channel floating-point image of the same size as disparity . Each element of _3dImage(x,y) contains 3D coordinates of the point (x,y) computed from the disparity map.
Q	4×4 perspective transformation matrix that can be obtained with stereoRectify.
handleMissingValues	Indicates, whether the function should handle missing values (i.e. points where the disparity was not computed). If handleMissingValues=true, then pixels with the minimal disparity that corresponds to the outliers (see **StereoMatcher::compute**) are transformed to 3D points with a very large Z value (currently set to 10000).
ddepth	The optional output array depth. If it is -1, the output image will have CV_32F depth. ddepth can also be set to CV_16S, CV_32S or CV_32F.

The function transforms a single-channel disparity map to a 3-channel image representing a 3D surface. That is, for each pixel (x,y) and the corresponding disparity d=disparity(x,y) , it computes:

$$[X \; Y \; Z \; W]^T = \texttt{Q} * [x \; y \; \texttt{disparity}(x,y) \; 1]^T$$
$$\texttt{\_3dImage}(x,y) = (X/W, \; Y/W, \; Z/W)$$

The matrix Q can be an arbitrary 4×4 matrix (for example, the one computed by stereoRectify). To reproject a sparse set of points {(x,y,d),...} to 3D space, use perspectiveTransform .

§ Rodrigues()

```
void cv::Rodrigues ( InputArray  src,
                     OutputArray dst,
                     OutputArray jacobian = noArray()
                   )
```

Python:

```
dst, jacobian = cv.Rodrigues( src[, dst[, jacobian]] )
```

Converts a rotation matrix to a rotation vector or vice versa.

Parameters

src	Input rotation vector (3x1 or 1x3) or rotation matrix (3x3).
dst	Output rotation matrix (3x3) or rotation vector (3x1 or 1x3), respectively.
jacobian	Optional output Jacobian matrix, 3x9 or 9x3, which is a matrix of partial derivatives of the output array components with respect to the input array components.

$$\theta \leftarrow norm(r)$$
$$r \leftarrow r/\theta$$
$$R = \cos\theta I + (1 - \cos\theta) r r^T + \sin\theta \begin{bmatrix} 0 & -r_z & r_y \\ r_z & 0 & -r_x \\ -r_y & r_x & 0 \end{bmatrix}$$

Inverse transformation can be also done easily, since

$$\sin(\theta) \begin{bmatrix} 0 & -r_z & r_y \\ r_z & 0 & -r_x \\ -r_y & r_x & 0 \end{bmatrix} = \frac{R - R^T}{2}$$

A rotation vector is a convenient and most compact representation of a rotation matrix (since any rotation matrix has just 3 degrees of freedom). The representation is used in the global 3D geometry optimization procedures like calibrateCamera, stereoCalibrate, or solvePnP .

Examples:

samples/cpp/tutorial_code/features2D/Homography/decompose_homography.cpp,
samples/cpp/tutorial_code/features2D/Homography/homography_from_camera_displacement.cpp, and
samples/cpp/tutorial_code/features2D/Homography/pose_from_homography.cpp.

§ RQDecomp3x3()

```
Vec3d cv::RQDecomp3x3 ( InputArray  src,
                        OutputArray mtxR,
                        OutputArray mtxQ,
                        OutputArray Qx = noArray(),
                        OutputArray Qy = noArray(),
                        OutputArray Qz = noArray()
                      )
```

Python:

```
retval, mtxR, mtxQ, Qx, Qy, Qz = cv.RQDecomp3x3( src[, mtxR[, mtxQ[, Qx[, Qy[, Qz]]]]] )
```

Computes an RQ decomposition of 3x3 matrices.

Parameters

src	3x3 input matrix.
mtxR	Output 3x3 upper-triangular matrix.
mtxQ	Output 3x3 orthogonal matrix.
Qx	Optional output 3x3 rotation matrix around x-axis.
Qy	Optional output 3x3 rotation matrix around y-axis.
Qz	Optional output 3x3 rotation matrix around z-axis.

The function computes a RQ decomposition using the given rotations. This function is used in decomposeProjectionMatrix to decompose the left 3x3 submatrix of a projection matrix into a camera and a rotation matrix.

It optionally returns three rotation matrices, one for each axis, and the three Euler angles in degrees (as the return value) that could be used in OpenGL. Note, there is always more than one sequence of rotations about the three principal axes that results in the same orientation of an object, e.g. see [173] . Returned tree rotation matrices and corresponding three Euler angles are only one of the possible solutions.

§ sampsonDistance()

double cv::sampsonDistance (**InputArray** pt1,
InputArray pt2,
InputArray F
)

Python:
retval = cv.sampsonDistance(pt1, pt2, F)

Calculates the Sampson Distance between two points.

The function **cv::sampsonDistance** calculates and returns the first order approximation of the geometric error as:

$$sd(\texttt{pt1}, \texttt{pt2}) = \frac{(\texttt{pt2}^t \cdot \texttt{F} \cdot \texttt{pt1})^2}{((\texttt{F} \cdot \texttt{pt1})(0))^2 + ((\texttt{F} \cdot \texttt{pt1})(1))^2 + ((\texttt{F}^t \cdot \texttt{pt2})(0))^2 + ((\texttt{F}^t \cdot \texttt{pt2})(1))^2}$$

The fundamental matrix may be calculated using the **cv::findFundamentalMat** function. See [77] 11.4.3 for details.

Parameters

pt1 first homogeneous 2d point

pt2 second homogeneous 2d point

F fundamental matrix

Returns

The computed Sampson distance.

§ solveP3P()

int cv::solveP3P (**InputArray** objectPoints,
InputArray imagePoints,
InputArray cameraMatrix,
InputArray distCoeffs,
OutputArrayOfArrays rvecs,
OutputArrayOfArrays tvecs,
int flags
)

Python:
retval, rvecs, tvecs = cv.solveP3P(objectPoints, imagePoints, cameraMatrix, distCoeffs, flags[, rvecs[, tvecs]])

Finds an object pose from 3 3D-2D point correspondences.

Parameters

objectPoints Array of object points in the object coordinate space, 3x3 1-channel or 1x3/3x1 3-channel. vector<Point3f> can be also passed here.

imagePoints Array of corresponding image points, 3x2 1-channel or 1x3/3x1 2-channel. vector<Point2f> can be also passed here.

cameraMatrix Input camera matrix $A = \begin{bmatrix} fx & 0 & cx \\ 0 & fy & cy \\ 0 & 0 & 1 \end{bmatrix}$.

distCoeffs Input vector of distortion coefficients $(k_1, k_2, p_1, p_2[, k_3[, k_4, k_5, k_6[, s_1, s_2, s_3, s_4[, \tau_x, \tau_y]]]])$ of 4, 5, 8, 12 or 14 elements. If the vector is NULL/empty, the zero distortion coefficients are assumed.

rvecs Output rotation vectors (see Rodrigues) that, together with tvecs , brings points from the model coordinate system to the camera coordinate system. A P3P problem has up to 4 solutions.

tvecs Output translation vectors.

flags Method for solving a P3P problem:

- **SOLVEPNP_P3P** Method is based on the paper of X.S. Gao, X.-R. Hou, J. Tang, H.-F. Chang "Complete Solution Classification for the Perspective-Three-Point Problem" ([64]).
- **SOLVEPNP_AP3P** Method is based on the paper of Tong Ke and Stergios I. Roumeliotis. "An Efficient Algebraic Solution to the Perspective-Three-Point Problem" ([96]).

The function estimates the object pose given 3 object points, their corresponding image projections, as well as the camera matrix and the distortion coefficients.

§ solvePnP()

```
bool cv::solvePnP ( InputArray  objectPoints,
                    InputArray  imagePoints,
                    InputArray  cameraMatrix,
                    InputArray  distCoeffs,
                    OutputArray rvec,
                    OutputArray tvec,
                    bool        useExtrinsicGuess = false,
                    int         flags = SOLVEPNP_ITERATIVE
                  )
```

Python:

```
retval, rvec, tvec = cv.solvePnP( objectPoints, imagePoints, cameraMatrix, distCoeffs[, rvec[, tvec[, useExtrinsicGuess[, flags]]]] )
```

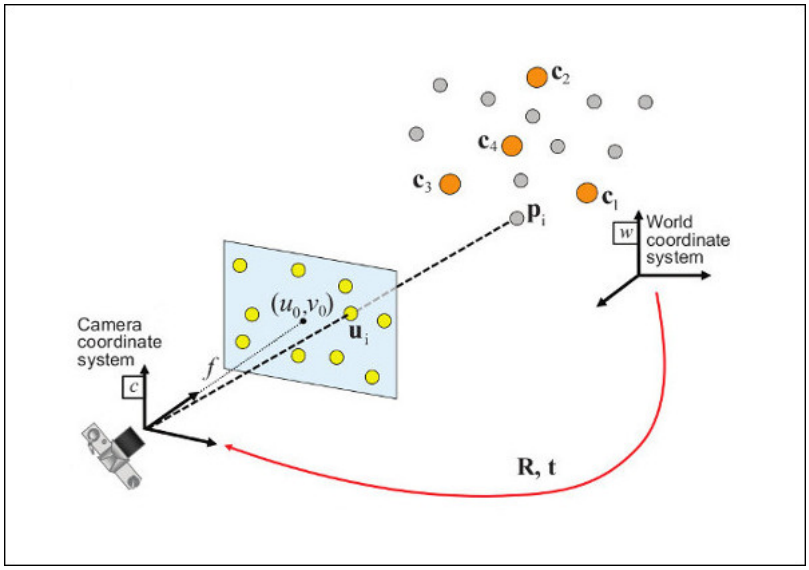
Finds an object pose from 3D-2D point correspondences.

Parameters

objectPoints	Array of object points in the object coordinate space, Nx3 1-channel or 1xN/Nx1 3-channel, where N is the number of points. vector<Point3f> can be also passed here.
imagePoints	Array of corresponding image points, Nx2 1-channel or 1xN/Nx1 2-channel, where N is the number of points. vector<Point2f> can be also passed here.
cameraMatrix	Input camera matrix $A = \begin{bmatrix} fx & 0 & cx \\ 0 & fy & cy \\ 0 & 0 & 1 \end{bmatrix}$.
distCoeffs	Input vector of distortion coefficients $(k_1, k_2, p_1, p_2[, k_3[, k_4, k_5, k_6[, s_1, s_2, s_3, s_4[, \tau_x, \tau_y]]]])$ of 4, 5, 8, 12 or 14 elements. If the vector is NULL/empty, the zero distortion coefficients are assumed.
rvec	Output rotation vector (see **Rodrigues**) that, together with tvec , brings points from the model coordinate system to the camera coordinate system.
tvec	Output translation vector.
useExtrinsicGuess	Parameter used for **SOLVEPNP_ITERATIVE**. If true (1), the function uses the provided rvec and tvec values as initial approximations of the rotation and translation vectors, respectively, and further optimizes them.
flags	Method for solving a PnP problem:

- **SOLVEPNP_ITERATIVE** Iterative method is based on Levenberg-Marquardt optimization. In this case the function finds such a pose that minimizes reprojection error, that is the sum of squared distances between the observed projections imagePoints and the projected (using projectPoints) objectPoints .
- **SOLVEPNP_P3P** Method is based on the paper of X.S. Gao, X.-R. Hou, J. Tang, H.-F. Chang "Complete Solution Classification for the Perspective-Three-Point Problem" (**[64]**). In this case the function requires exactly four object and image points.
- **SOLVEPNP_AP3P** Method is based on the paper of **T**. Ke, S. Roumeliotis "An Efficient Algebraic Solution to the Perspective-Three-Point Problem" (**[96]**). In this case the function requires exactly four object and image points.
- **SOLVEPNP_EPNP** Method has been introduced by F.Moreno-Noguer, V.Lepetit and P.Fua in the paper "EPnP: Efficient Perspective-n-Point Camera Pose Estimation" (**[107]**).
- **SOLVEPNP_DLS** Method is based on the paper of Joel A. Hesch and Stergios I. Roumeliotis. "A Direct Least-Squares (DLS) Method for PnP" (**[84]**).
- **SOLVEPNP_UPNP** Method is based on the paper of A.Penate-Sanchez, J.Andrade-Cetto, F.Moreno-Noguer. "Exhaustive Linearization for Robust Camera Pose and Focal Length Estimation" (**[148]**). In this case the function also estimates the parameters f_x and f_y assuming that both have the same value. Then the cameraMatrix is updated with the estimated focal length.
- **SOLVEPNP_AP3P** Method is based on the paper of Tong Ke and Stergios I. Roumeliotis. "An Efficient Algebraic Solution to the Perspective-Three-Point Problem" (**[96]**). In this case the function requires exactly four object and image points.

The function estimates the object pose given a set of object points, their corresponding image projections, as well as the camera matrix and the distortion coefficients, see the figure below (more precisely, the X-axis of the camera frame is pointing to the right, the Y-axis downward and the Z-axis forward).



Points expressed in the world frame $\mathbf{X_w}$ are projected into the image plane $[u, v]$ using the perspective projection model Π and the camera intrinsic parameters matrix $\mathbf{A}$:

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \mathbf{A} \, \Pi \, {}^{c}\mathbf{M_w} \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix}$$

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_x \\ r_{21} & r_{22} & r_{23} & t_y \\ r_{31} & r_{32} & r_{33} & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix}$$

The estimated pose is thus the rotation (`rvec`) and the translation (`tvec`) vectors that allow to transform a 3D point expressed in the world frame into the camera frame:

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix} = {}^{c}\mathbf{M_w} \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix}$$

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_x \\ r_{21} & r_{22} & r_{23} & t_y \\ r_{31} & r_{32} & r_{33} & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix}$$

Note

- An example of how to use solvePnP for planar augmented reality can be found at opencv_source_code/samples/python/plane_ar.py
- If you are using Python:
  - Numpy array slices won't work as input because solvePnP requires contiguous arrays (enforced by the assertion using **cv::Mat::checkVector()** around line 55 of modules/calib3d/src/solvepnp.cpp version 2.4.9)
  - The P3P algorithm requires image points to be in an array of shape (N,1,2) due to its calling of **cv::undistortPoints** (around line 75 of modules/calib3d/src/solvepnp.cpp version 2.4.9) which requires 2-channel information.
  - Thus, given some data D = np.array(...) where D.shape = (N,M), in order to use a subset of it as, e.g., imagePoints, one must effectively copy it into a new array: imagePoints = np.ascontiguousarray(D[:,:2]).reshape((N,1,2))
- The methods **SOLVEPNP_DLS** and **SOLVEPNP_UPNP** cannot be used as the current implementations are unstable and sometimes give completely wrong results. If you pass one of these two flags, **SOLVEPNP_EPNP** method will be used instead.
- The minimum number of points is 4 in the general case. In the case of **SOLVEPNP_P3P** and **SOLVEPNP_AP3P** methods, it is required to use exactly 4 points (the first 3 points are used to estimate all the solutions of the P3P problem, the last one is used to retain the best solution that minimizes the reprojection error).
- With **SOLVEPNP_ITERATIVE** method and `useExtrinsicGuess=true`, the minimum number of points is 3 (3 points are sufficient to compute a pose but there are up to 4 solutions). The initial solution should be close to the global solution to converge.

Examples:

samples/cpp/tutorial_code/features2D/Homography/decompose_homography.cpp, and
samples/cpp/tutorial_code/features2D/Homography/homography_from_camera_displacement.cpp.

§ solvePnPRansac()

```
bool cv::solvePnPRansac ( InputArray  objectPoints,
                          InputArray  imagePoints,
                          InputArray  cameraMatrix,
                          InputArray  distCoeffs,
                          OutputArray rvec,
                          OutputArray tvec,
                          bool        useExtrinsicGuess = false,
                          int         iterationsCount = 100,
                          float       reprojectionError = 8.0,
                          double      confidence = 0.99,
                          OutputArray inliers = noArray(),
                          int         flags = SOLVEPNP_ITERATIVE
                        )
```

Python:

```
retval,
rvec,
tvec,
inliers = cv.solvePnPRansac( objectPoints, imagePoints, cameraMatrix, distCoeffs[, rvec[, tvec[, useExtrinsicGuess[, iterationsCount[, reprojectionError[, confidence[
```

Finds an object pose from 3D-2D point correspondences using the RANSAC scheme.

Parameters

objectPoints	Array of object points in the object coordinate space, Nx3 1-channel or 1xN/Nx1 3-channel, where N is the number of points. vector<Poir passed here.
imagePoints	Array of corresponding image points, Nx2 1-channel or 1xN/Nx1 2-channel, where N is the number of points. vector<Point2f> can be als
cameraMatrix	Input camera matrix $A = \begin{bmatrix} fx & 0 & cx \\ 0 & fy & cy \\ 0 & 0 & 1 \end{bmatrix}$.
distCoeffs	Input vector of distortion coefficients $(k_1, k_2, p_1, p_2[, k_3[, k_4, k_5, k_6[, s_1, s_2, s_3, s_4[, \tau_x, \tau_y]]]])$ of 4, 5, 8, 12 or 14 elements. If the vec the zero distortion coefficients are assumed.
rvec	Output rotation vector (see Rodrigues) that, together with tvec , brings points from the model coordinate system to the camera coordinat
tvec	Output translation vector.
useExtrinsicGuess	Parameter used for SOLVEPNP_ITERATIVE. If true (1), the function uses the provided rvec and tvec values as initial approximations of t translation vectors, respectively, and further optimizes them.
iterationsCount	Number of iterations.
reprojectionError	Inlier threshold value used by the RANSAC procedure. The parameter value is the maximum allowed distance between the observed an projections to consider it an inlier.
confidence	The probability that the algorithm produces a useful result.
inliers	Output vector that contains indices of inliers in objectPoints and imagePoints .
flags	Method for solving a PnP problem (see solvePnP).

The function estimates an object pose given a set of object points, their corresponding image projections, as well as the camera matrix and the distortion coefficients such a pose that minimizes reprojection error, that is, the sum of squared distances between the observed projections imagePoints and the projected (using projectP objectPoints. The use of RANSAC makes the function resistant to outliers.

Note

- An example of how to use solvePNPRansac for object detection can be found at opencv_source_code/samples/cpp/tutorial_code/calib3d/real_time_pos
- The default method used to estimate the camera pose for the Minimal Sample Sets step is **SOLVEPNP_EPNP**. Exceptions are:
  - if you choose **SOLVEPNP_P3P** or **SOLVEPNP_AP3P**, these methods will be used.
  - if the number of input points is equal to 4, **SOLVEPNP_P3P** is used.
- The method used to estimate the camera pose using all the inliers is defined by the flags parameters unless it is equal to **SOLVEPNP_P3P** or **SOLVEPI** case, the method **SOLVEPNP_EPNP** will be used instead.

§ stereoCalibrate() [1/2]

```
double cv::stereoCalibrate ( InputArrayOfArrays objectPoints,
                             InputArrayOfArrays imagePoints1,
                             InputArrayOfArrays imagePoints2,
                             InputOutputArray   cameraMatrix1,
                             InputOutputArray   distCoeffs1,
                             InputOutputArray   cameraMatrix2,
                             InputOutputArray   distCoeffs2,
                             Size               imageSize,
                             InputOutputArray   R,
                             InputOutputArray   T,
                             OutputArray        E,
                             OutputArray        F,
                             OutputArray        perViewErrors,
                             int                flags = CALIB_FIX_INTRINSIC,
                             TermCriteria       criteria = TermCriteria(TermCriteria::COUNT+TermCriteria::EPS, 30, 1e-6)
                           )
```

Python:

```
retval,
cameraMatrix1,
distCoeffs1,
cameraMatrix2,
distCoeffs2, R,
T, E, F
                = cv.stereoCalibrate(          objectPoints, imagePoints1, imagePoints2, cameraMatrix1, distCoeffs1, cameraMatrix2, distCoeffs2, imageSize[, R[,
retval,
cameraMatrix1,
distCoeffs1,
cameraMatrix2,
distCoeffs2, R,
T, E, F,
perViewErrors
                = cv.stereoCalibrateExtended( objectPoints, imagePoints1, imagePoints2, cameraMatrix1, distCoeffs1, cameraMatrix2, distCoeffs2, imageSize, R, T
```

Calibrates the stereo camera.

Parameters

objectPoints	Vector of vectors of the calibration pattern points.
imagePoints1	Vector of vectors of the projections of the calibration pattern points, observed by the first camera.
imagePoints2	Vector of vectors of the projections of the calibration pattern points, observed by the second camera.
cameraMatrix1	Input/output first camera matrix: $\begin{bmatrix} f_x^{(j)} & 0 & c_x^{(j)} \\ 0 & f_y^{(j)} & c_y^{(j)} \\ 0 & 0 & 1 \end{bmatrix}$, $j = 0,\ 1$. If any of CALIB_USE_INTRINSIC_GUESS , CALIB_FIX_ASPECT_RATI CALIB_FIX_FOCAL_LENGTH are specified, some or all of the matrix components must be initialized. See the flags description for details.
distCoeffs1	Input/output vector of distortion coefficients $(k_1, k_2, p_1, p_2[, k_3[, k_4, k_5, k_6[, s_1, s_2, s_3, s_4[, \tau_x, \tau_y]]]])$ of 4, 5, 8, 12 or 14 elements. The ou
cameraMatrix2	Input/output second camera matrix. The parameter is similar to cameraMatrix1
distCoeffs2	Input/output lens distortion coefficients for the second camera. The parameter is similar to distCoeffs1 .
imageSize	Size of the image used only to initialize intrinsic camera matrix.
R	Output rotation matrix between the 1st and the 2nd camera coordinate systems.
T	Output translation vector between the coordinate systems of the cameras.
E	Output essential matrix.
F	Output fundamental matrix.
perViewErrors	Output vector of the RMS re-projection error estimated for each pattern view.
flags	Different flags that may be zero or a combination of the following values:

- **CALIB_FIX_INTRINSIC** Fix cameraMatrix? and distCoeffs? so that only R, T, E , and F matrices are estimated.
- **CALIB_USE_INTRINSIC_GUESS** Optimize some or all of the intrinsic parameters according to the specified flags. Initial values are pr
- **CALIB_USE_EXTRINSIC_GUESS** R, T contain valid initial values that are optimized further. Otherwise R, T are initialized to the medi dimension separately).
- **CALIB_FIX_PRINCIPAL_POINT** Fix the principal points during the optimization.
- **CALIB_FIX_FOCAL_LENGTH** Fix $f_x^{(j)}$ and $f_y^{(j)}$.
- **CALIB_FIX_ASPECT_RATIO** Optimize $f_y^{(j)}$. Fix the ratio $f_x^{(j)}/f_y^{(j)}$
- **CALIB_SAME_FOCAL_LENGTH** Enforce $f_x^{(0)} = f_x^{(1)}$ and $f_y^{(0)} = f_y^{(1)}$.
- **CALIB_ZERO_TANGENT_DIST** Set tangential distortion coefficients for each camera to zeros and fix there.
- **CALIB_FIX_K1,...,CALIB_FIX_K6** Do not change the corresponding radial distortion coefficient during the optimization. If CALIB_USE coefficient from the supplied distCoeffs matrix is used. Otherwise, it is set to 0.

- **CALIB_RATIONAL_MODEL** Enable coefficients k4, k5, and k6. To provide the backward compatibility, this extra flag should be explici function use the rational model and return 8 coefficients. If the flag is not set, the function computes and returns only 5 distortion coeffic
- **CALIB_THIN_PRISM_MODEL** Coefficients s1, s2, s3 and s4 are enabled. To provide the backward compatibility, this extra flag shoulc calibration function use the thin prism model and return 12 coefficients. If the flag is not set, the function computes and returns only 5 d
- **CALIB_FIX_S1_S2_S3_S4** The thin prism distortion coefficients are not changed during the optimization. If CALIB_USE_INTRINSIC_ supplied distCoeffs matrix is used. Otherwise, it is set to 0.
- **CALIB_TILTED_MODEL** Coefficients tauX and tauY are enabled. To provide the backward compatibility, this extra flag should be expli function use the tilted sensor model and return 14 coefficients. If the flag is not set, the function computes and returns only 5 distortion
- **CALIB_FIX_TAUX_TAUY** The coefficients of the tilted sensor model are not changed during the optimization. If CALIB_USE_INTRINS the supplied distCoeffs matrix is used. Otherwise, it is set to 0.

criteria Termination criteria for the iterative optimization algorithm.

The function estimates transformation between two cameras making a stereo pair. If you have a stereo camera where the relative position and orientation of two cam of an object relative to the first camera and to the second camera, (R1, T1) and (R2, T2), respectively (this can be done with solvePnP), then those poses definitely r given (R_1, T_1), it should be possible to compute (R_2, T_2). You only need to know the position and orientation of the second camera relative to the first camera. Th computes (R, T) so that:

$$R_2 = R * R_1$$
$$T_2 = R * T_1 + T,$$

Optionally, it computes the essential matrix E:

$$E = \begin{bmatrix} 0 & -T_2 & T_1 \\ T_2 & 0 & -T_0 \\ -T_1 & T_0 & 0 \end{bmatrix} * R$$

where T_i are components of the translation vector $T : T = [T_0, T_1, T_2]^T$. And the function can also compute the fundamental matrix F:

$$F = cameraMatrix2^{-T} E cameraMatrix1^{-1}$$

Besides the stereo-related information, the function can also perform a full calibration of each of two cameras. However, due to the high dimensionality of the parame function can diverge from the correct solution. If the intrinsic parameters can be estimated with high accuracy for each of the cameras individually (for example, using recommended to do so and then pass CALIB_FIX_INTRINSIC flag to the function along with the computed intrinsic parameters. Otherwise, if all the parameters are restrict some parameters, for example, pass CALIB_SAME_FOCAL_LENGTH and CALIB_ZERO_TANGENT_DIST flags, which is usually a reasonable assumption.

Similarly to calibrateCamera , the function minimizes the total re-projection error for all the points in all the available views from both cameras. The function returns th

§ stereoCalibrate() [2/2]

```
double cv::stereoCalibrate ( InputArrayOfArrays objectPoints,
                             InputArrayOfArrays imagePoints1,
                             InputArrayOfArrays imagePoints2,
                             InputOutputArray cameraMatrix1,
                             InputOutputArray distCoeffs1,
                             InputOutputArray cameraMatrix2,
                             InputOutputArray distCoeffs2,
                             Size imageSize,
                             OutputArray R,
                             OutputArray T,
                             OutputArray E,
                             OutputArray F,
                             int flags = CALIB_FIX_INTRINSIC,
                             TermCriteria criteria = TermCriteria(TermCriteria::COUNT+TermCriteria::EPS, 30, 1e-6)
                           )
```

Python:

```
retval,
cameraMatrix1,
distCoeffs1,
cameraMatrix2,
distCoeffs2, R,
T, E, F = cv.stereoCalibrate( objectPoints, imagePoints1, imagePoints2, cameraMatrix1, distCoeffs1, cameraMatrix2, distCoeffs2, imageSize[, R[, T
```

```
retval,
cameraMatrix1,
distCoeffs1,
cameraMatrix2,
distCoeffs2, R,
T, E, F,
perViewErrors = cv.stereoCalibrateExtended( objectPoints, imagePoints1, imagePoints2, cameraMatrix1, distCoeffs1, cameraMatrix2, distCoeffs2, imageSize, R, T
```

This is an overloaded member function, provided for convenience. It differs from the above function only in what argument(s) it accepts.

§ stereoRectify()

```
void cv::stereoRectify ( InputArray  cameraMatrix1,
                         InputArray  distCoeffs1,
                         InputArray  cameraMatrix2,
                         InputArray  distCoeffs2,
                         Size        imageSize,
                         InputArray  R,
                         InputArray  T,
                         OutputArray R1,
                         OutputArray R2,
                         OutputArray P1,
                         OutputArray P2,
                         OutputArray Q,
                         int         flags = CALIB_ZERO_DISPARITY,
                         double      alpha = -1,
                         Size        newImageSize = Size(),
                         Rect *      validPixROI1 = 0,
                         Rect *      validPixROI2 = 0
                       )
```

Python:

```
R1, R2, P1, P2, Q, validPixROI1, validPixROI2 = cv.stereoRectify( cameraMatrix1, distCoeffs1, cameraMatrix2, distCoeffs2, imageSize, R, T[, R1[, R2[, P1[, P2[, Q[, flags[, alpha[, newImageSize]]]]]]]] )
```

Computes rectification transforms for each head of a calibrated stereo camera.

Parameters

cameraMatrix1	First camera matrix.
distCoeffs1	First camera distortion parameters.
cameraMatrix2	Second camera matrix.
distCoeffs2	Second camera distortion parameters.
imageSize	Size of the image used for stereo calibration.
R	Rotation matrix between the coordinate systems of the first and the second cameras.
T	Translation vector between coordinate systems of the cameras.
R1	Output 3x3 rectification transform (rotation matrix) for the first camera.
R2	Output 3x3 rectification transform (rotation matrix) for the second camera.
P1	Output 3x4 projection matrix in the new (rectified) coordinate systems for the first camera.
P2	Output 3x4 projection matrix in the new (rectified) coordinate systems for the second camera.
Q	Output 4×4 disparity-to-depth mapping matrix (see reprojectImageTo3D).
flags	Operation flags that may be zero or CALIB_ZERO_DISPARITY . If the flag is set, the function makes the principal points of each camera hav the same pixel coordinates in the rectified views. And if the flag is not set, the function may still shift the images in the horizontal or vertical direction (depending on the orientation of epipolar lines) to maximize the useful image area.
alpha	Free scaling parameter. If it is -1 or absent, the function performs the default scaling. Otherwise, the parameter should be between 0 and 1. alpha=0 means that the rectified images are zoomed and shifted so that only valid pixels are visible (no black areas after rectification). alpha=1 means that the rectified image is decimated and shifted so that all the pixels from the original images from the cameras are retained in the rectified images (no source image pixels are lost). Obviously, any intermediate value yields an intermediate result between those two extreme cases.
newImageSize	New image resolution after rectification. The same size should be passed to initUndistortRectifyMap (see the stereo_calib.cpp sample in OpenCV samples directory). When (0,0) is passed (default), it is set to the original imageSize . Setting it to larger value can help you preserv details in the original image, especially when there is a big radial distortion.
validPixROI1	Optional output rectangles inside the rectified images where all the pixels are valid. If alpha=0 , the ROIs cover the whole images. Otherwise, they are likely to be smaller (see the picture below).
validPixROI2	Optional output rectangles inside the rectified images where all the pixels are valid. If alpha=0 , the ROIs cover the whole images. Otherwise, they are likely to be smaller (see the picture below).

The function computes the rotation matrices for each camera that (virtually) make both camera image planes the same plane. Consequently, this makes all the epipolar lines parallel and thus simplifies the dense stereo correspondence problem. The function takes the matrices computed by stereoCalibrate as input. As outpu it provides two rotation matrices and also two projection matrices in the new coordinates. The function distinguishes the following two cases:

- **Horizontal stereo**: the first and the second camera views are shifted relative to each other mainly along the x axis (with possible small vertical shift). In the rectified images, the corresponding epipolar lines in the left and right cameras are horizontal and have the same y-coordinate. P1 and P2 look like:

$$\texttt{P1} = \begin{bmatrix} f & 0 & cx_1 & 0 \\ 0 & f & cy & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

$$\texttt{P2} = \begin{bmatrix} f & 0 & cx_2 & T_x * f \\ 0 & f & cy & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix},$$

where T_x is a horizontal shift between the cameras and $cx_1 = cx_2$ if CALIB_ZERO_DISPARITY is set.

- **Vertical stereo**: the first and the second camera views are shifted relative to each other mainly in vertical direction (and probably a bit in the horizontal directio too). The epipolar lines in the rectified images are vertical and have the same x-coordinate. P1 and P2 look like:

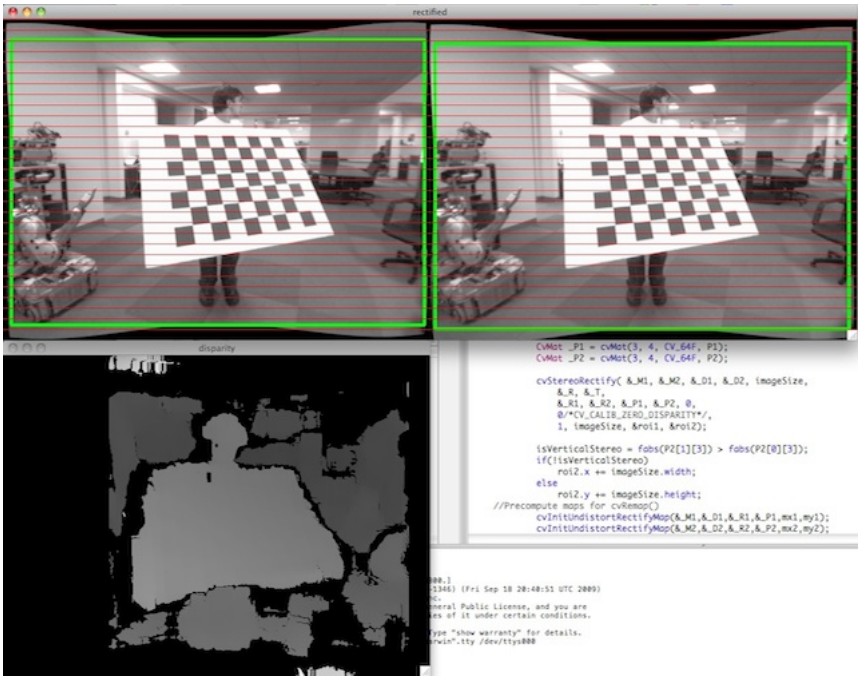
$$\texttt{P1} = \begin{bmatrix} f & 0 & cx & 0 \\ 0 & f & cy_1 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

$$\texttt{P2} = \begin{bmatrix} f & 0 & cx & 0 \\ 0 & f & cy_2 & T_y * f \\ 0 & 0 & 1 & 0 \end{bmatrix},$$

where T_y is a vertical shift between the cameras and $cy_1 = cy_2$ if CALIB_ZERO_DISPARITY is set.

As you can see, the first three columns of P1 and P2 will effectively be the new "rectified" camera matrices. The matrices, together with R1 and R2 , can then be passed to initUndistortRectifyMap to initialize the rectification map for each camera.

See below the screenshot from the stereo_calib.cpp sample. Some red horizontal lines pass through the corresponding image regions. This means that the images are well rectified, which is what most stereo correspondence algorithms rely on. The green rectangles are roi1 and roi2 . You see that their interiors are all valid pixels



image

§ stereoRectifyUncalibrated()

```
bool cv::stereoRectifyUncalibrated ( InputArray  points1,
                                     InputArray  points2,
                                     InputArray  F,
                                     Size        imgSize,
                                     OutputArray H1,
                                     OutputArray H2,
                                     double      threshold = 5
                                   )
```

Python:

```
retval, H1, H2 = cv.stereoRectifyUncalibrated( points1, points2, F, imgSize[, H1[, H2[, threshold]]] )
```

Computes a rectification transform for an uncalibrated stereo camera.

Parameters

points1	Array of feature points in the first image.
points2	The corresponding points in the second image. The same formats as in findFundamentalMat are supported.
F	Input fundamental matrix. It can be computed from the same set of point pairs using findFundamentalMat .
imgSize	Size of the image.
H1	Output rectification homography matrix for the first image.
H2	Output rectification homography matrix for the second image.
threshold	Optional threshold used to filter out the outliers. If the parameter is greater than zero, all the point pairs that do not comply with the epipolar geometry (that is, the points for which $\left\|\texttt{points2[i]}^T * \texttt{F} * \texttt{points1[i]}\right\| > \texttt{threshold}$) are rejected prior to computing the homographies. Otherwise, all the points are considered inliers.

The function computes the rectification transformations without knowing intrinsic parameters of the cameras and their relative position in the space, which explains the suffix "uncalibrated". Another related difference from stereoRectify is that the function outputs not the rectification transformations in the object (3D) space, but the planar perspective transformations encoded by the homography matrices H1 and H2 . The function implements the algorithm **[78]** .

Note

While the algorithm does not need to know the intrinsic parameters of the cameras, it heavily depends on the epipolar geometry. Therefore, if the camera lenses have a significant distortion, it would be better to correct it before computing the fundamental matrix and calling this function. For example, distortion coefficients can be estimated for each head of stereo camera separately by using calibrateCamera . Then, the images can be corrected using undistort , or just the point coordinates can be corrected with undistortPoints .

§ triangulatePoints()

```
void cv::triangulatePoints ( InputArray  projMatr1,
                             InputArray  projMatr2,
                             InputArray  projPoints1,
                             InputArray  projPoints2,
                             OutputArray points4D
                           )
```

Python:

```
points4D = cv.triangulatePoints( projMatr1, projMatr2, projPoints1, projPoints2[, points4D] )
```

Reconstructs points by triangulation.

Parameters

projMatr1	3x4 projection matrix of the first camera.
projMatr2	3x4 projection matrix of the second camera.
projPoints1	2xN array of feature points in the first image. In case of c++ version it can be also a vector of feature points or two-channel matrix of size 1xN or Nx1.
projPoints2	2xN array of corresponding points in the second image. In case of c++ version it can be also a vector of feature points or two-channel matrix of size 1xN or Nx1.
points4D	4xN array of reconstructed points in homogeneous coordinates.

The function reconstructs 3-dimensional points (in homogeneous coordinates) by using their observations with a stereo camera. Projections matrices can be obtained from stereoRectify.

Note

Keep in mind that all input data should be of float type in order for this function to work.

See also

reprojectImageTo3D

§ validateDisparity()

```
void cv::validateDisparity ( InputOutputArray  disparity,
                             InputArray        cost,
                             int               minDisparity,
                             int               numberOfDisparities,
                             int               disp12MaxDisp = 1
                            )
```

Python:

```
disparity = cv.validateDisparity( disparity, cost, minDisparity, numberOfDisparities[, disp12MaxDisp] )
```

validates disparity using the left-right check. The matrix "cost" should be computed by the stereo correspondence algorithm