**RECTIFICATION**

Image rectification is a transformation process used to project images onto a common image plane. This process has several degrees of freedom and there are many strategies for transforming images to the common plane. Image rectification is used in [computer stereo vision](https://en.wikipedia.org/wiki/Computer_stereo_vision) to simplify the problem of finding matching points between images (i.e. the [correspondence problem](https://en.wikipedia.org/wiki/Correspondence_problem)), and in [geographic information systems](https://en.wikipedia.org/wiki/Geographic_information_system) (GIS) to merge images taken from multiple perspectives into a common map coordinate system.

All rectified images satisfy the following two properties:[[8]](https://en.wikipedia.org/wiki/Image_rectification#cite_note-ZHANG2009-8)

* All epipolar lines are parallel to the horizontal axis.
* Corresponding points have identical vertical coordinates.

In order to transform the original image pair into a rectified image pair, it is necessary to find a [projective transformation](https://en.wikipedia.org/wiki/Projective_transformation) *H*. Constraints are placed on *H* to satisfy the two properties above. For example, constraining the epipolar lines to be parallel with the horizontal axis means that epipoles must be mapped to the infinite point *[1,0,0]T* in [homogeneous coordinates](https://en.wikipedia.org/wiki/Homogeneous_coordinates). Even with these constraints, *H* still has four degrees of freedom. It is also necessary to find a matching *H'*to rectify the second image of an image pair. Poor choices of *H* and *H'*can result in rectified images that are dramatically changed in scale or severely distorted.

In computer vision, rectification is a process that transforms stereo images to align corresponding points along the same row, effectively making the images appear as though they were taken from parallel cameras. This alignment simplifies the stereo correspondence problem, allowing for easier matching of features and depth estimation.

**Key aspects of image rectification:**

**Purpose:**

To align corresponding points in a stereo image pair along the same rows, making it easier to find corresponding features.

**Process:**

Rectification involves applying a projective transformation (homography) to each image, mapping epipolar lines to horizontal scanlines.

**Benefits:**

Simplifies stereo correspondence: Reduces the search space for matching points to a single horizontal scanline, making it more efficient and robust.

Enables depth estimation: Once rectified, the disparity between corresponding points can be used to estimate depth in a 3D scene.

Facilitates image stitching and mosaicking: Rectification can be used to align images from different perspectives for creating panoramic views.

**Techniques:**

Various algorithms can be used for rectification, including:

Planar rectification: Aligns the image planes to a common plane.

Cylindrical rectification: Uses a cylindrical projection to warp images.

Polar rectification: Applies a polar transformation to align images.

**Applications:**

Rectification is widely used in stereo vision, image vision, 3D reconstruction, and other computer vision tasks where aligning images from different viewpoints is crucial.

**1. Stereo Rectification – Key Concepts & Formulas**

**Epipolar Geometry Basics**

* **Fundamental Matrix (F):**  
  Relates corresponding points in stereo images:

x′TFx=0\mathbf{x'}^T \mathbf{F} \mathbf{x} = 0x′TFx=0

where x,x′\mathbf{x}, \mathbf{x'}x,x′ are corresponding points in left and right images.

* **Epipolar Lines:** After rectification, these become horizontal (same row in both images).

**Rectification Transforms**

* Each image is warped using **rotation matrices** R1R\_1R1​, R2R\_2R2​ and **projection matrices** P1P\_1P1​, P2P\_2P2​:

P1=K[R1∣0],P2=K[R2∣T]P\_1 = K [R\_1 \mid 0], \quad P\_2 = K [R\_2 \mid T]P1​=K[R1​∣0],P2​=K[R2​∣T]

where KKK is the intrinsic matrix and TTT is the translation between cameras.

* The rectification maps can be computed using OpenCV's stereoRectify().

**Disparity and Depth**

* After rectification, the **disparity** ddd is:

d=xleft−xrightd = x\_{\text{left}} - x\_{\text{right}}d=xleft​−xright​

* Depth (Z) from disparity:

Z=f⋅BdZ = \frac{f \cdot B}{d}Z=df⋅B​

where:

* + fff: focal length,
  + BBB: baseline (distance between cameras),
  + ddd: disparity.

2**. Image Rectification – Key Concepts & Formulas**

**Camera Model**

* A 3D point X\mathbf{X}X is projected to an image point x\mathbf{x}x:

x=K[R∣t]X\mathbf{x} = K [R \mid t] \mathbf{X}x=K[R∣t]X

where KKK is the camera intrinsic matrix, and R,tR, tR,t are rotation and translation.

**Lens Distortion Correction**

* Common distortion types: radial and tangential:

xcorrected=x(1+k1r2+k2r4+… )+2p1xy+p2(r2+2x2)x\_{\text{corrected}} = x (1 + k\_1 r^2 + k\_2 r^4 + \dots) + 2p\_1 x y + p\_2 (r^2 + 2x^2)xcorrected​=x(1+k1​r2+k2​r4+…)+2p1​xy+p2​(r2+2x2)

where:

* + k1,k2,…k\_1, k\_2, \dotsk1​,k2​,…: radial distortion coefficients
  + p1,p2p\_1, p\_2p1​,p2​: tangential distortion coefficients
  + r2=x2+y2r^2 = x^2 + y^2r2=x2+y2

**Homography for Planar Rectification**

* Maps a plane in one image to another:

x′=Hx\mathbf{x'} = H \mathbf{x}x′=Hx

HHH is a 3×3 homography matrix (used in cv2.getPerspectiveTransform() or cv2.findHomography()).

**1. Stereo Rectification**

In stereo vision systems (using two or more cameras), **rectification** refers to:

* **Aligning the image planes** of the stereo pair so that corresponding points lie on the same horizontal line.
* This simplifies the search for **matching points** to a 1D search along epipolar lines (which become horizontal lines after rectification).

**Why it's needed:**

* Makes stereo matching faster and more accurate.
* Essential for depth estimation using disparity maps.

**How it's done:**

* Using **camera calibration** parameters (intrinsics and extrinsics).
* Applying **homographies** or **rotation matrices** to warp the images.

**2. Image Rectification (Geometric Correction)**

This involves correcting distortions due to:

* Lens distortion (barrel, pincushion, etc.)
* Perspective distortion (e.g., tilted images of planar surfaces)

**Used in:**

* Document scanning (to get top-down views)
* Mapping aerial/satellite images to a flat coordinate system (orthorectification)

**How it's done:**

* Using camera intrinsics and distortion coefficients.
* Applying transformations (e.g., homography, affine) to align image geometry.

**1. Stereo Rectification**

**Advantages:**

* **Simplifies stereo matching:** Corresponding points lie on the same row (epipolar lines become horizontal).
* **Improves accuracy:** Reduces ambiguity in disparity computation for depth estimation.
* **Enables efficient algorithms:** Disparity search becomes 1D instead of 2D, speeding up stereo processing.
* **Makes visualization easier:** Epipolar geometry is easier to understand and debug.

**Disadvantages:**

* **Depends on accurate calibration:** Poor camera calibration leads to incorrect rectification.
* **May cause image cropping or black borders:** Warping can distort or remove parts of the image.
* **Computational cost:** Homography computation and warping add processing overhead.
* **Not helpful if cameras are not stereo-aligned:** Arbitrary camera arrangements can make rectification complex or infeasible.

**2. Image Rectification (Geometric/Perspective Correction)**

**Advantages:**

* **Corrects distortion:** Removes lens and perspective distortion, making images more usable for analysis.
* **Improves measurement accuracy:** Useful in mapping, 3D modeling, and document scanning.
* **Standardizes viewpoints:** Makes comparison across images easier.

**Disadvantages:**

* **Requires prior calibration or feature knowledge:** Accurate parameters or keypoint matching is essential.
* **Possible loss of resolution/details:** Interpolation during warping may degrade image quality.
* **Computational overhead:** Can be expensive for high-resolution or real-time processing.
* **Doesn't handle non-planar scenes well:** For scenes with depth variation, simple rectification may distort 3D structure.