Image Analysis

Algorithms for Edge Detection

Technical University
of Applied Sciences
Würzburg-Schweinfurt

Canny Edge Detector

- Low pass Filtering
- Image Gradients
- Non-maximum Suppression
- Threshold classification
- Contour Tracking by Hysteresis

Hough Transformation

- Idea of Hough Transformation
- Hough Space
- Line Representations
- Lines in Hough Space

Canny Edge Detector - Algorithm

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The Canny edge detector is one of the most popular image processing techniques for extracting contours in a gray-scale image. It consists of five sub-steps.

Steps of the algorithm

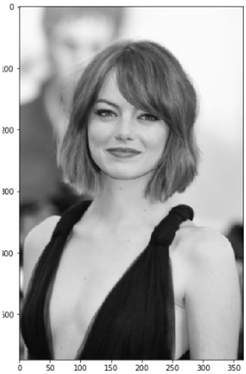
- Low pass filtering
- Calculation of the gradient
- Non-maximum suppression
- Classification by thresholds
- Edge tracking

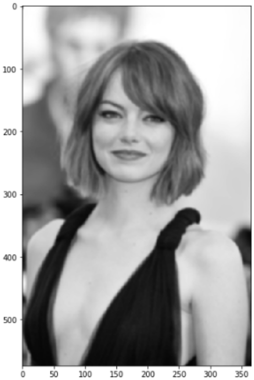
The algorithm was published in 1986 by John Francis Canny in the journal *Pattern Analysis and Machine Intelligence*.

Canny Edge Detector

Low pass Filtering

In the first step, high-frequency image noise is removed with a 2D low-pass filter, e.g. a binomial filter. This also smoothes the edges somewhat.





Canny Edge Detector

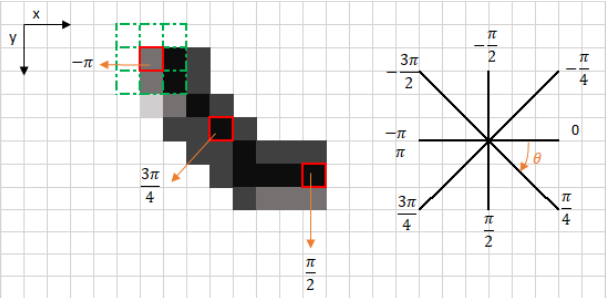
Calculation of the Gradient

In the second step, the Sobel operator is used to determine the gradient vector for each pixel. From this, the direction of the strongest change and the gradient strength are calculated.

Canny Edge Detector

Non-maximum Suppression

In the third step, the values of the gradient strength along the orientation are compared in a neighborhood of 3x3 pixels. If there is a higher value in the neighborhood than the value at the anchor point, then the value of the anchor point is set to zero. Otherwise it remains.

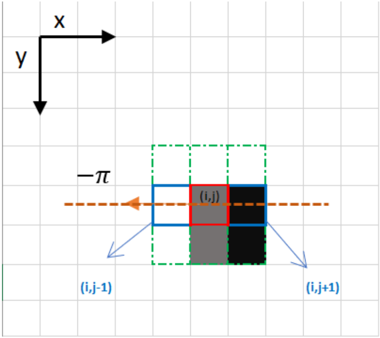


Canny Edge Detector

Non-maximum Suppression

Examples for Non Maximum Suppression

Is the value of the pixel at the anchor point suppressed or not?



Canny Edge Detector

Non-maximum Suppression

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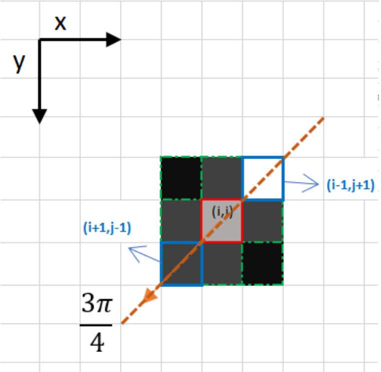
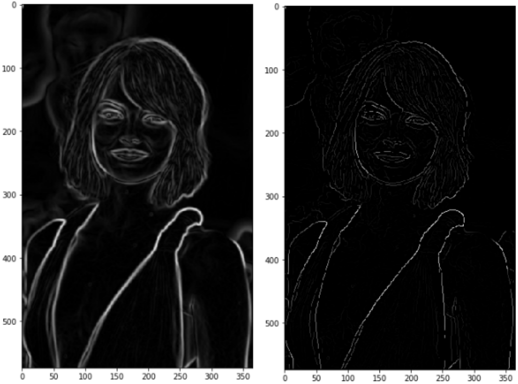
Examples for Non Maximum Suppression

Is the value of the pixel at the anchor point suppressed or not?



Non-maximum Suppression

Example of the result of suppression of non-maximum values. The result is a thinned gradient strength image.

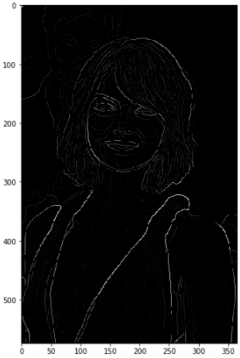


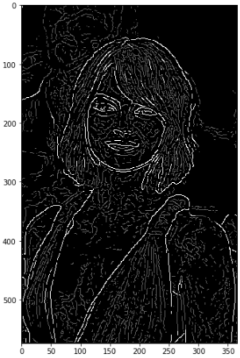
Canny Edge Detector

Classification by Thresholds

In the fourth step, the gradient strength is divided into three classes by means of two threshold values $\tau_1 > \tau_2$.

If the gradient strength is above the larger threshold, then the pixel is assigned the class strong edge $K = 2$. If the gradient strength is below the smaller threshold, then the pixel is assigned the class no edge $K = 0$. If the gradient strength is between both thresholds, then the pixel is assigned the class weak edge $K = 1$.

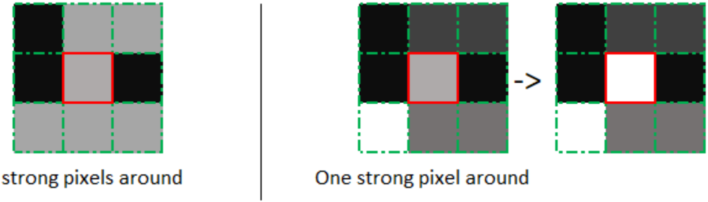




Canny Edge Detector

Edge Tracking via Hysteresis

In the last step, for each pixel classified as a weak edge, a check is made to see if there is a pixel in a 3x3 neighborhood that was classified as a strong edge. If this is the case, then the class is changed from weak edge to strong edge.



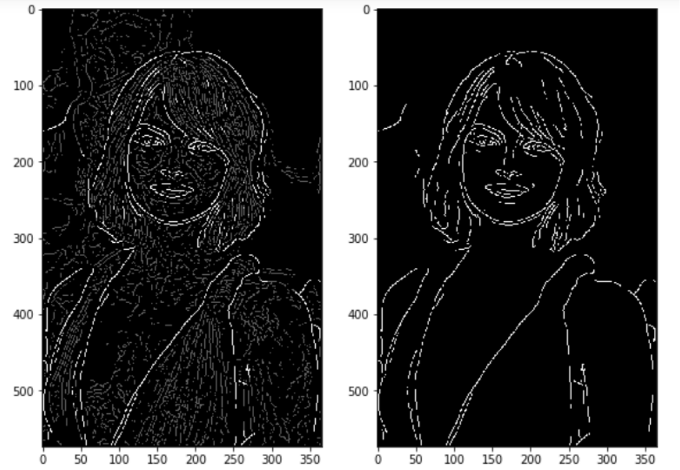
No strong pixels around

One strong pixel around

Canny Edge Detector

Result

Canny Edge Image



Hough Transformation - Idea

Using the Hough transformation, the pixels of an edge image can be assigned to simple geometric shapes, such as straight lines or circles. The Hough transformation is a robust method of geometric image segmentation.

Requirements for use

- A parametric function of the geometric shape exists
- A binary image of the contours exists

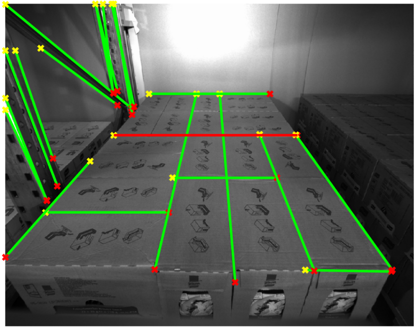
The algorithm was patented by Paul Hough in 1962. One of the first applications of the Hough transformation was implemented on the Shakey mobile robot at the Stanford Research Institute's Artificial Intelligence Laboratory.

Roboter Shakey

Image Analysis

Hough Transformation - Example

Input image



Output image

Hough Transformation Algorithm

The algorithm for segmentation of geometric shapes can be divided into five steps.

Steps of the algorithm

- Select geometric shape and parameterization
- Create binary edge image
- Perform Hough transformation
- Find maxima in Hough space
- Assign pixels to the set of all extracted shapes

There are some extensions to this basic variant. For example, the edge strength can be taken into account, or the assignment of edge pixels to the set of models can be made more efficient and robust by probabilistic methods. These extensions are not considered here.

Hough Transformation

Image Space and Hough Space

Transformation from Image space to Hough space

The Hough transform transforms each pixel $K(m, n)$ in the 2D image space of an edge image $\mathbf{K}$ to a curve $h_{m,n}(\mathbf{p}) = 0$ in the P-dimensional Hough space $H(\mathbf{p})$. The vector $\mathbf{p} = \{p_i\}_{i=1}^{P}$ corresponds to the P parameters of the Hough space.

The parameters of the Hough space span all possible expressions of a geometric shape over a certain discretized range of values of parameters of the geometric shape. This can be, for example, all slopes and y-intercepts of a set of different straight lines in an image.

Each point in Hough space corresponds to a geometric shape $f_{\mathbf{p}}(m, n) = 0$ with fixed parameters $\mathbf{p}$, for example, a particular straight line in image space.

Hough Transformation

Image Space and Hough Space

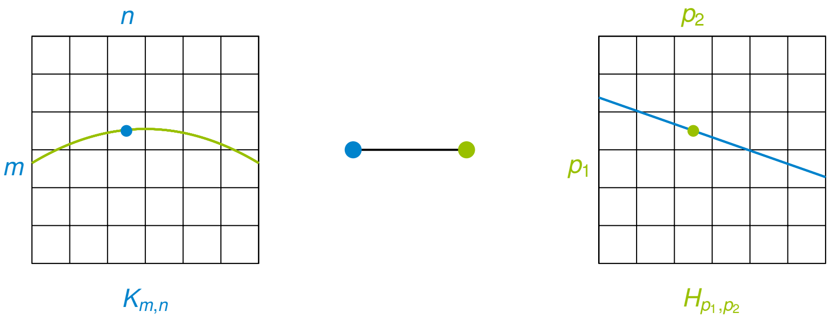


Image Space

$f_{\mathbf{p}}(m, n) = 0$

Hough Space

$h_{m,n}(\mathbf{p}) = 0$

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Example Lines - Choose Parameterization

The simplest geometric form to segment a contour section in an edge image is the straight line. Therefore, we will look at the individual steps using the example of the Hough transformation for straight lines.

Possible parameterizations of a straight line

- Slope and y-intercept: $y = m \cdot x + t$
- Hessian normal form: $\rho = x \cdot \cos(\theta) + y \cdot \sin(\theta)$

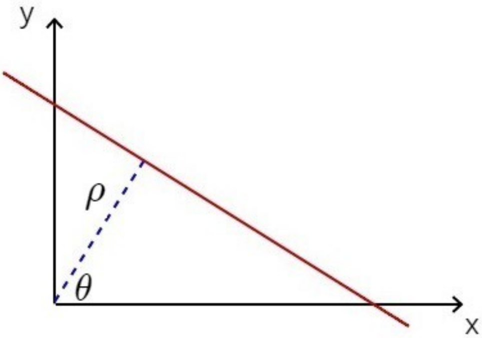
Why is the Hessian normal form the appropriate parameterization for a Hough transformation?

Hough Transformation

Example Lines - Choose Parameterization

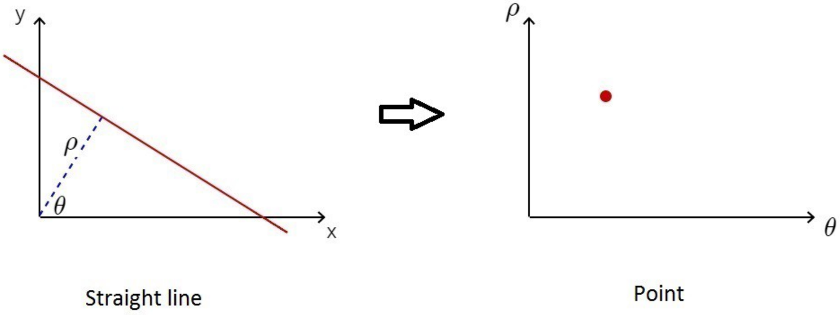
Suitable parameterization of a straight line for the Hough space

- Hessian normal form: $\rho = x \cdot \cos(\theta) + y \cdot \sin(\theta)$



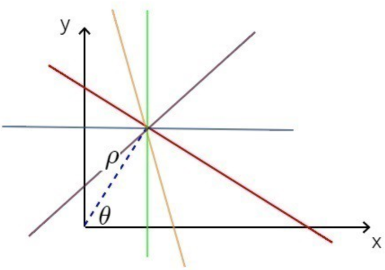
Example Lines - Hough Transformation

A straight line in image space corresponds to a point in Hough space.

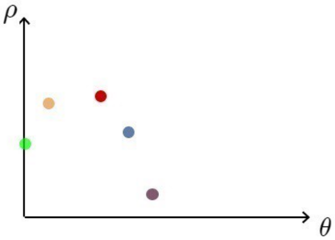


Example Lines - Hough Transformation

Straight lines in image space that intersect at a point result in a sine in Hough space.



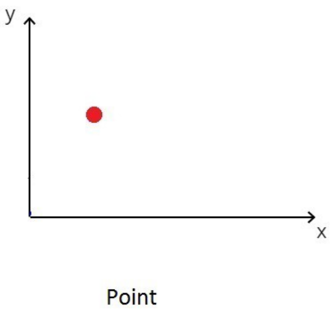
Bunch of lines intersecting at one point

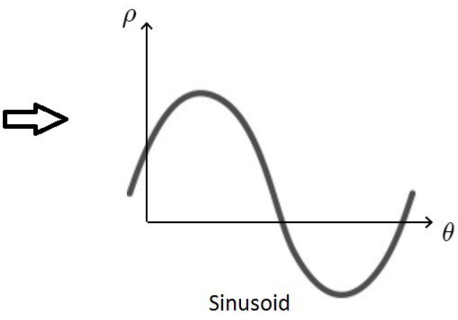


Points which form a sinusoid

Example Lines - Hough Transformation

A point in the image space corresponds to a sine curve in Hough space.

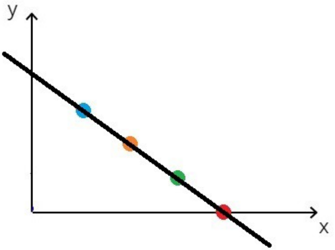




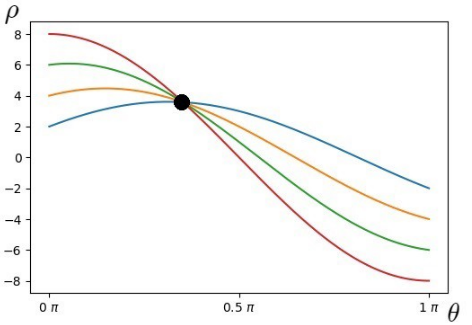
Hough Transformation

Example Lines - Hough Transformation

Points on a straight line in image space correspond to different sinusoids in Hough space that intersect at a point.



Points which form a line



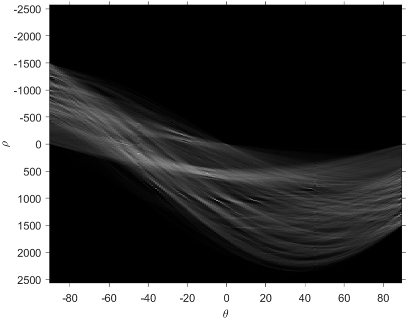
Bunch of sinusoids intersecting at one point

Hough Transformation

Example Lines - Hough Transformation

The number of sinusoids that intersect at a point in Hough space is entered as a vote in the Hough matrix.

Binary edge image

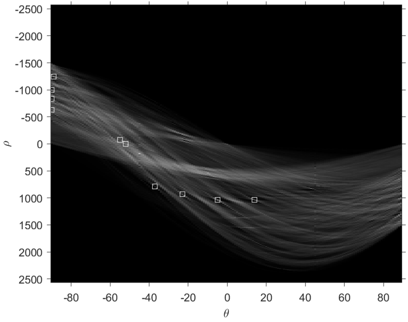


Votes in Hough matrix

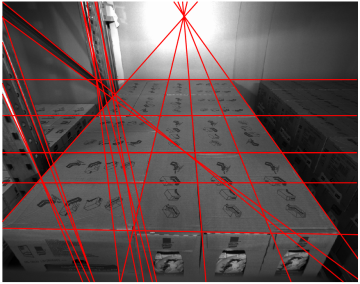
Hough Transformation

Example Lines - Extraction of Lines

The maxima of the votes are extracted as candidates for possible straight lines in the image space.



Maxima of Votes

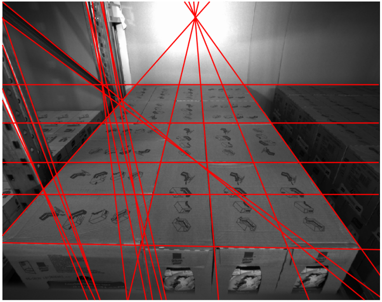


Lines in image space

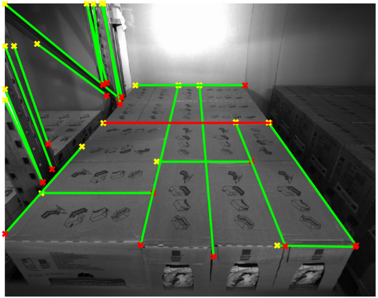
Hough Transformation

Example Lines - Segmentation of Edge Image

All pixels of the edge image that lie on one of the straight lines are grouped (segmented) into a straight line segment.



Lines in image space



Line segments