The Hough Transform

combined with anisotropic Distance Transform for robust segmentation of seedlings

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- **Theory**
  - **discrete geometry, 2D & 3D**
  - **fuzzy methods**
- **Biomedical**
  - **microscopic data (cytometry)**
  - **tomographic data**
- **Visualization and computer graphics**
  - **haptics**
- **Forestry related applications**
  - **inner structure of paper**
- **Remote sensing**
  - **tracking effects of global warming**

Content

- The application: Seed growth quantification
- Very quick overview of the developed method (image in, numbers out)
- The Hough transform
  - detecting lines
  - detecting circles

- Back to the application
- Summary

The application

Image analysis for quantitative estimation of seed vitality

- ThermoSeed™ cereal seed treatment is a new **method for thermal seed treatment** developed by SeedGard AB.
- Makes it possible to produce seed free from seed-borne pathogens **without using chemicals**.
- By exposing seeds with precisely conditioned **hot humid air**, pathogens are killed without affecting seed vitality.
- It is of interest to facilitate **objective and accurate monitoring** of how different treatments and different types of stress affects the vitality of the seeds.

Task and method

1. Let plants grow in a controlled environment
2. Take photos of the plants after a certain time
3. Count and measure area and length of grown plants
4. Make statistical analysis

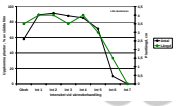


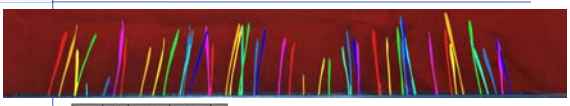
Photo straight from the side

Controlled imaging environment
Red background = good contrast

Algorithm in brief

- Read 14-bit raw from camera (dcraw)
- White balance image
- Change of colour space: RGB -> HLS
- Find plants (green), box (blue) and background (red)
  - Colour classification (hue and saturation)
  - Morphological operations (“grow” / “shrink”)
- Find top of box (as reference)
- Identify connected plants (labelling)
- Clean away too small regions
- For each connected region
  - split the region into separate plants using iterated Hough transform
- Measure area and length of the plants

Program: image in, numbers out



	A	B	C
1	ID	diam	area
2	1	264	2712
3	2	286	2431
4	3	179	2234
5	4	210	1624
6	5	48	267
7	6	79	625
8	7	48	225
9	8	292	2915
10	9	221	1684
11	10	190	1566
12	11	226	1613
13	12	265	2671
14	13	257	1780
15	14	266	1894
16	15	263	2109
17	16	266	2471

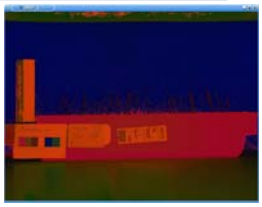
Fully automatic

- Table with length and area of each plant
- Colour coded segmented image (as reference/verification)

Input 14 bit raw RGB

White balance

Change of colour space RGB->HLS

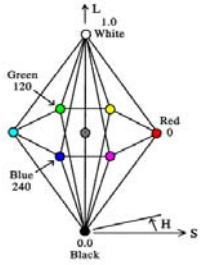


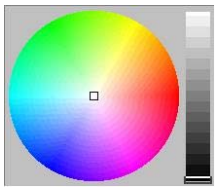
RGB
Red Green Blue

HLS
Hue Lightness Saturation

To minimize the effect of changes in illumination and thereby simplify colour based classification

HLS color space – Hue Lightness Saturation



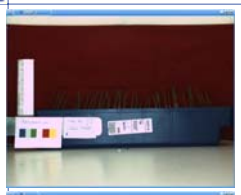


Hue=dominant wavelength, tone
Lightness=intensity, brightness
Saturation=purity, fullness

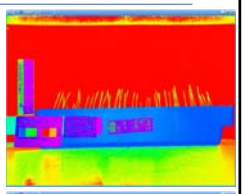
- Intensity decoupled from colour tone
- More similar to how humans perceive colour

Change of colour space RGB->HLS

RGB

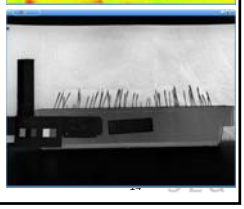


Hue



Light-ness

Satu-ration



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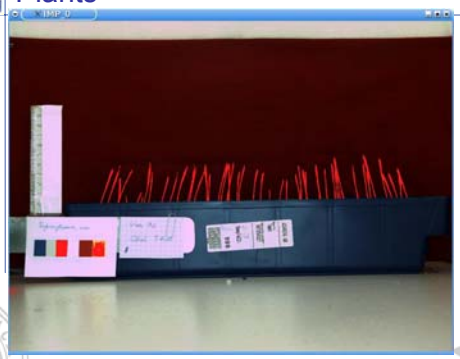
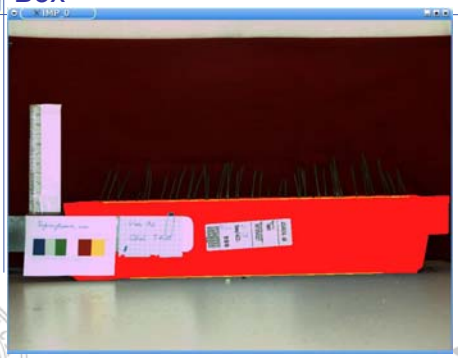
Plants

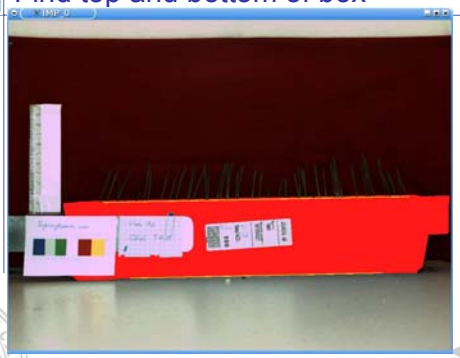


Box



Background (certainly not plant)

Find top and bottom of box



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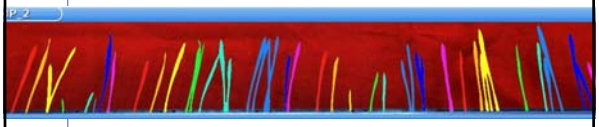
Label connected components



Mathematical morphology is used to bridge small gaps.

Mathematical morphology is a powerful tool for the image analyst. ☺

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The Hough Transform

Hough transform

From the universal source of knowledge: WIKIPEDIA

The Hough transform (pronounced / hʌf/, rhymes with tough) is a feature extraction technique used in image analysis, computer vision, and digital image processing. The purpose of the technique is to find imperfect instances of objects within a certain class of shapes by a voting procedure. This voting procedure is carried out in a parameter space, from which object candidates are obtained as local maxima in a so-called accumulator space that is explicitly constructed by the algorithm for computing the Hough transform.

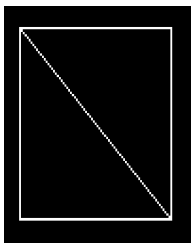
Hough transform

- A standard tool in image analysis that allows the recognition of a shape in an image space by the recognition of a point in a parameter space.
- Requirement: A low dimensional parameter representation of the pattern searched for.
- Particularly useful when the patterns searched for are sparsely digitized, have holes and/or the pictures are noisy.

P.V.C. Hough, Machine Analysis of Bubble Chamber Pictures, International Conference on High Energy Accelerators and Instrumentation, CERN, 1959.

Finding lines - The basic idea

Each straight line in an image can be described by an equation with a number of parameters, e.g. y=kx+m.



Each white point, if considered alone, could lie on an infinite number of straight lines.

In the Hough transform each point **votes** for every line it could be on.

The lines with the most votes win.

Finding lines - The basic idea

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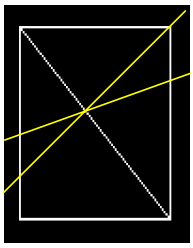

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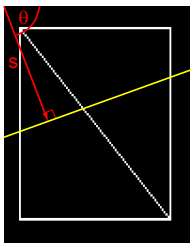
The lines with the most votes win.

How do we represent a line?

Any (infinitely long) straight line can be represented by two numbers



Here we will represent the yellow line by

1. the smallest distance ***s*** between the line and the origin
2. the angle **θ** of the locus vector from the origin to the point of smallest distance

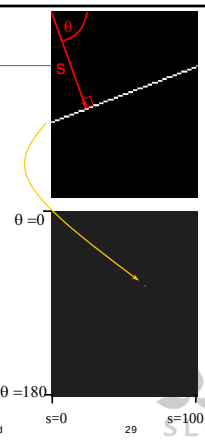
The values of ***s*** and **θ** are bounded.

Hough space

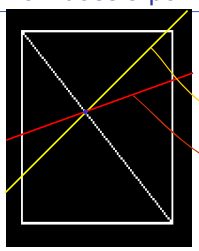
We can use (θ, s) to represent any line in the image space

That is, any line in the image space is represented by a single point in the parameter space defined by (θ, s)

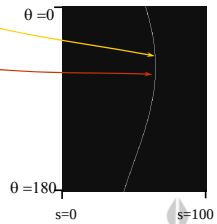
The parameter space is also called the Hough space or the accumulator



How does a point in image space vote?



$$s = x\cos(\theta) + y\sin(\theta)$$



One point in image space corresponds to a sinusoidal curve in Hough space

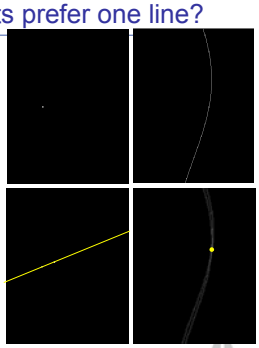
How do multiple points prefer one line?

One point in image space corresponds to a sinusoidal curve in Hough space

Two points correspond to two curves in Hough space

The intersection of those two curves has "two votes".

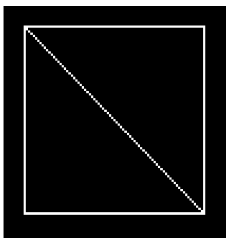
This intersection represents the straight line in the image space that passes through both points

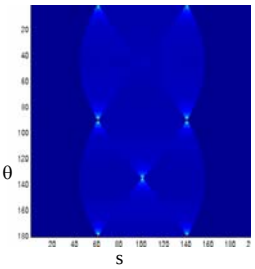


Hough Transform, implementation

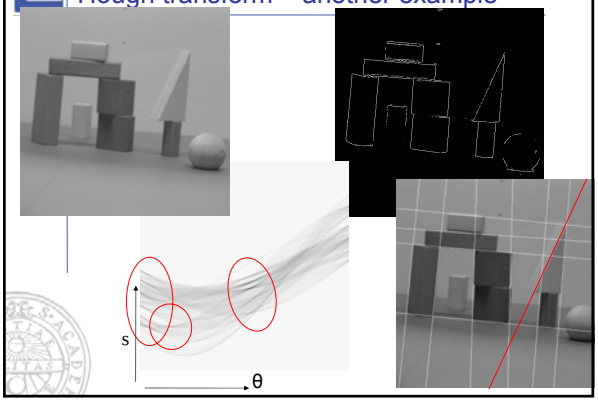
```
Create an empty array A,
  indexed by θ and s

for each possible line point (x,y)
  for each angle θ
      s = x*cos(θ)+ y*sin(θ)
      A[θ,s] = A[θ,s]+1
  end
end

where A is "big" return the line (θ, s)
```


A simple example

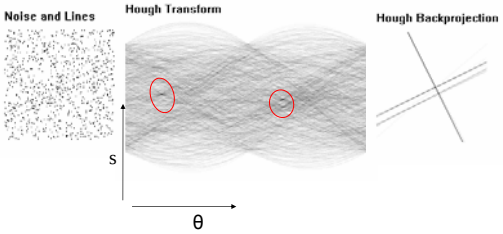




Hough transform – another example



Noise and broken lines



The Hough transform is robust with respect to intensity variations, noise, and partial object visibility.

Hough transform - *finding straight lines*

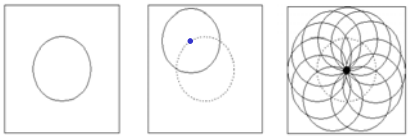
- Any straight line can be described with two parameters (θ,s), this corresponds to a single point in a 2D parameter space.
- For every point in the image, that is on a possible line, mark in the Hough image all lines that go through the given point.
- A true line in the image will get many "votes" in the Hough image;
  peaks in the Hough image = probable lines in the original image.
- Very similar to the discrete Radon transform used in tomography.

Parameters and properties

- How big should the cells be? (too big, and we merge quite different lines; too small, and noise causes lines to be missed)
- How many lines?
  - Count the peaks in the Hough array
  - Treat adjacent peaks as a single peak
- Which points belong to each line?
  - Search for points close to the line
  - Solve again for line and iterate
- Gradient information can be used to reduce computational load

Hough-transform to find circles

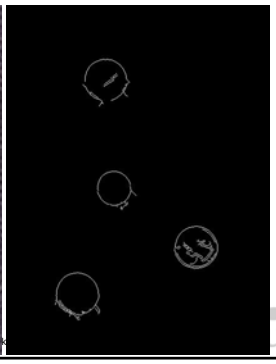
- Same idea $(x-x_c)^2+(y-y_c)^2=r^2$
  - A circle of a given radius can be described with 2 parameters, i.e., its centre (x_c,y_c).
  - A single image point draws a circle in the Hough image
  - A circle in the image forms a "star" of circles in the Hough image



Finding Coins

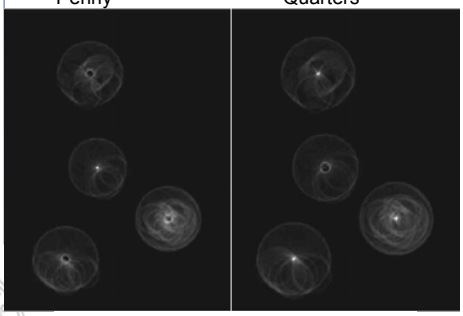
Original

Edges – Canny edge detector (note noise)



Finding Coins – different radii

Penny Quarters



A correct radius gives a well focused transform image
Measure the entropy of the Hough image

Finding Coins – result

Since the quarters and the penny have different sizes, two different Hough transforms, with separate accumulators, are used.

If the radii are unknown, then we use a 3D Hough space instead.

Hough transform

- Classical Hough Transform can locate regular curves like straight lines, circles, parabolas, ellipses, etc.
  - Requires that the shape can be specified in some parametric form
- Generalized Hough Transform can be used where a simple analytic description of the shape is not possible
  - similar to template matching
  - computationally heavy

Returning to our plants…

Back to our plants

Subtask: Split each labelled region into individual plants

Each plant is *more or less* a straight line

The edge based Hough transform is not very tolerant to shape variations

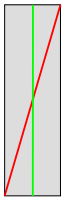
We instead accumulate points from the whole object region

Back to our plants

We want the detected line to be centered in the region

Give central pixels a higher importance

Use a *Distance Transform* to assign a *weight* to each object pixel



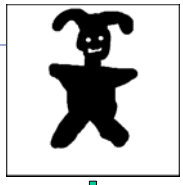
Distance transform (DT)

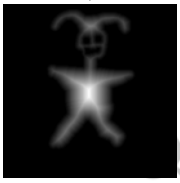
For each pixel of a region, compute the distance to the background.

Classical problem in discrete geometry

From the DT we can compute:

- various features (local width,...)
- shape representations
  medial axis or skeleton

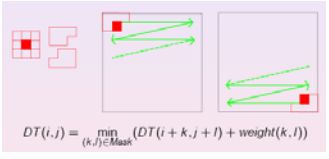




Sequential algorithm to compute locally weighted DT

Initialization:

$$DT(i,j) = 0 \quad if \quad (i,j) \notin Object$$
$$DT(i,j) = +\infty \quad if \quad (i,j) \in Object$$



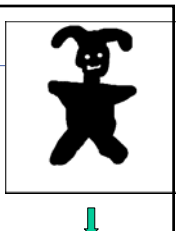
$$DT(i,j) = \min_{(k,l) \in Mask} (DT(i+k, j+l) + weight(k,l))$$

4	3	4
3	0	

3 × 3 mask

	11		11	
11	7	5	7	11
	5	0		

5 × 5 mask

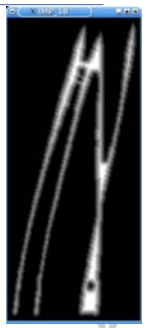


Distance transform

For each pixel of a region, compute the distance to the background.

	11		11	
11	7	5	7	11
	5	0		

5 × 5 mask (isotropic)



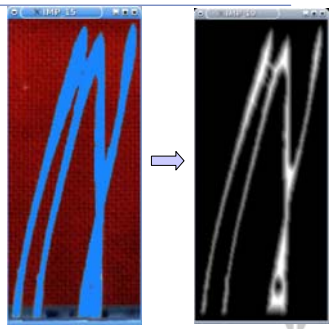
Non-isotropic distance transform

Different costs for different directions

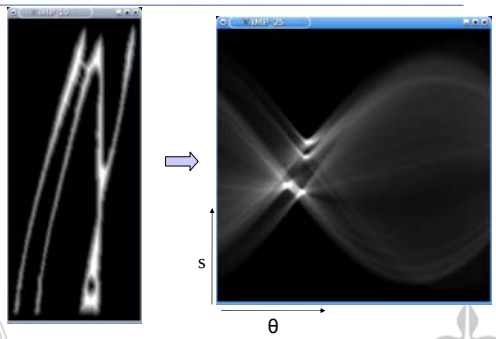
Twice the cost in horizontal direction

	17		17	
25	14	6	14	25
	12	0		

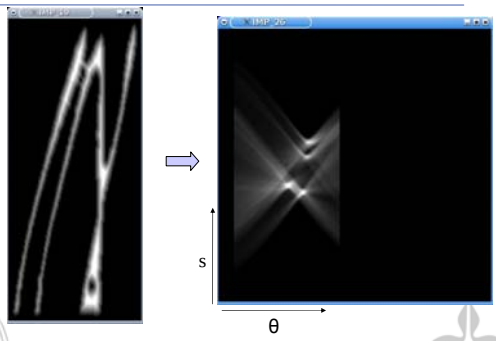
5 × 5 mask (non-isotropic)



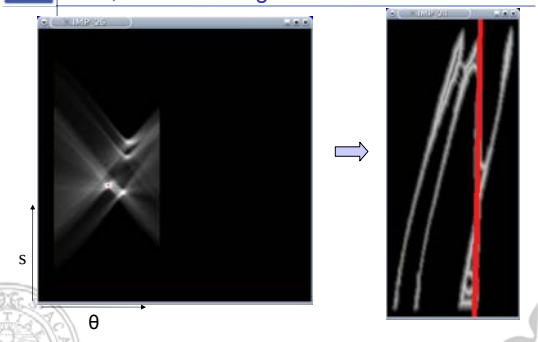
Hough transform



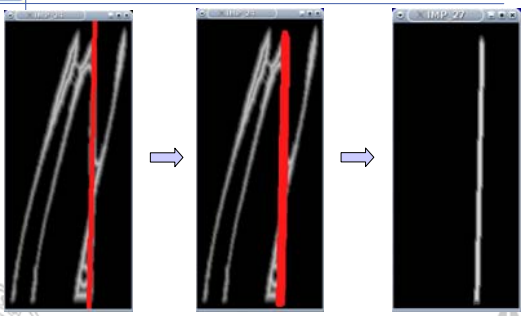
Restrict angles to [-35,35] degrees



Iteratively remove the strongest line, one at a time, until no strong lines left

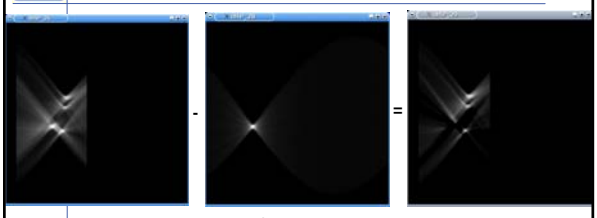


Extract line, mask in image (simulate plant), compute new distance transform…



Line | Dilated and masked | Distance transform

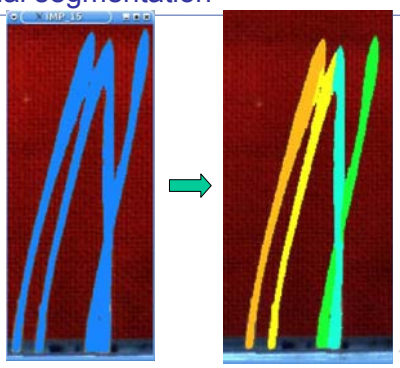
Subtract line from Hough image



The Hough transform is linear; we can add and subtract directly in the Hough image.

and then pick the next strongest signal...

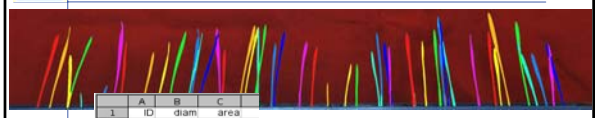
Final segmentation



Algorithm in brief

- Read 12-bit raw-format (dcraw)
- White balance image
- Change of colour space: RGB -> HLS
- Find plants (green), box (blue) and background (red)
  - Colour classification (hue and saturation)
  - Morphological operations (“grow” / “shrink”)
- Find top of box (as reference)
- Identify connected plants (labelling)
- Clean away too small regions
- For each region
  - split the region into separate plants using iterated Hough transform
- **Measure area and length of the plants**

Compute area and length

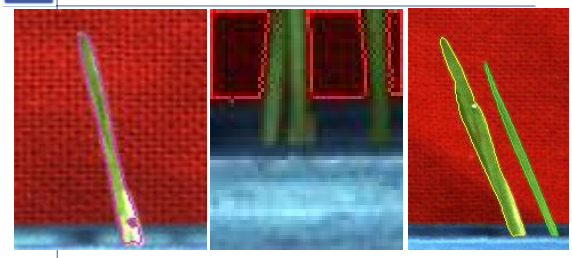


	A	B	C
1	ID	diam	area
2	1	264	2712
3	2	286	2431
4	3	179	2234
5	4	210	1624
6	5	48	267
7	6	79	625
8	7	48	225
9	8	292	2915
10	9	221	1684
11	10	190	1566
12	11	226	1613
13	12	265	2671
14	13	257	1780
15	14	266	1894
16	15	263	2109
17	16	266	2471

Area = count pixels

Length = from top to base-line along the found straight line

Problematic situations



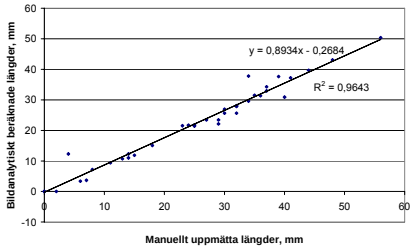
a) Soil b) Small background c) Overlap

Use fuzzy segmentation instead of crisp!

Results

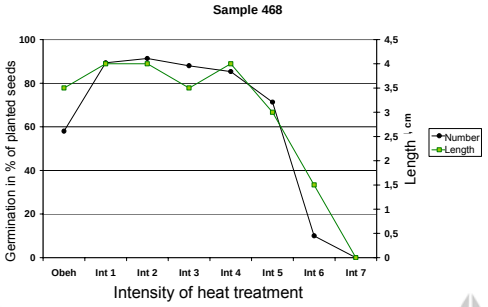
- Does it work?

Regression model



Works very well
- Slightly better(!) than manual length measures
- Occasionally misses small plants

Enables statistics on seed vitality as a function of seed treatment



One more example

Automatic Liquid Chromatography Rack Recognition

Isolera Flash Purification System

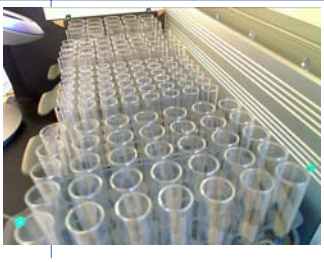
Biotage

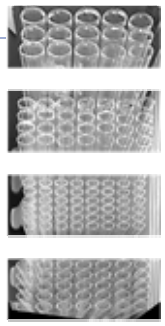
Master thesis Project by Johannes Löwén
February-June 2008

Supervisors: Joakim Lindblad, CBA
Ola Strandberg, Biotage

Problem: Determine which positions of each rack contain vials, and of what type.

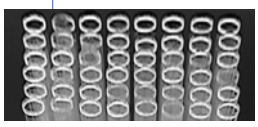
Typical image



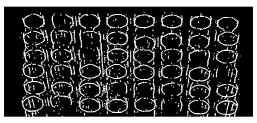


Known geometry, rectification is easy

Find ellipses (with know axes)

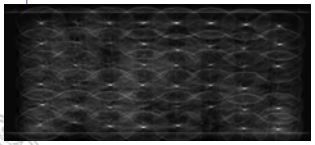


Edges



Contrast of glass edges is not very good

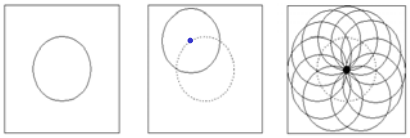
Hough to find ellipses



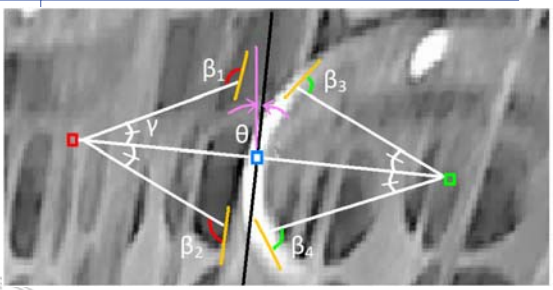
The Hough transform contains a lot of false maxima in between the vials.

Hough-transform to find circles

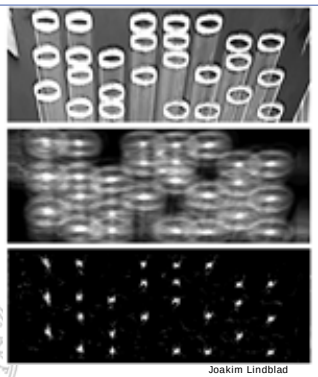
- Same idea $(x-x_c)^2+(y-y_c)^2=r^2$
  - A circle of a given radius can be described with 2 parameters, i.e., its centre (x_c,y_c).
  - A single image point draws a circle in the Hough image
  - A circle in the image forms a "star" of circles in the Hough image



Refining Hough by use of local orientation



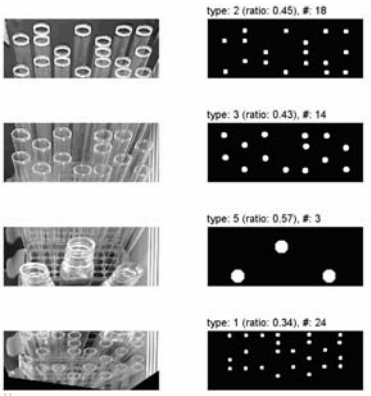
Combining Hough and local orientation



Input image

Standard Hough, does not care about local image structure

Refined Hough, using local edge orientation



Conclusions

- The Hough transform is a powerful tool for finding structures in images. (Very useful for “tracking” applications.)
- By giving a weight to each vote according to relevance/certainty increased robustness and increased tolerance to shape variations is achieved. (Fuzzy thinking is good for you!)
- The Hough image can often be enhanced by use of local image structure.

Conclusions 2 – Know your toolbox

- Colour based classification
- Morphological operations
- Hough transform
- Distance transform
- Local orientation
- …

Good knowledge of existing tools and methods will bring you far

Thank you for your attention