Image and Video Analysis

Dmitrij Csetverikov

Eötvös Loránd University, Budapest, Hungary
csetverikov@inf.elte.hu
csetverikov@sztaki.hu

Faculty of Informatics

Detection of curves of known shape

Model fitting of multiple structures 1/2

- Image can contains various structures
  - shapes, curves
- **Chicken-and-egg problem**
  - → for model estimation: segment image
  - → for segmentation: assign model to data
- Robustness to outliers
  - **gross** outliers: do not fit either of structures
  - **pseudo** outliers: do not fit selected structure
  - → but fit other structure

Model fitting of multiple structures 2/2

- Robustness to missing, noisy data
  - occlusions
  - missing measurements
  - distortions, noise
- The problem arises in many important applications, e.g.,
  - homography estimation
  - 3D object segmentation
  - motion segmentation
  - shape and curve detection

Non-parametric methods

- RANSAC
  - consensus: single model
- Multi-RANSAC
  - consensus: extension to multiple models
- FLoSS
  - consensus: multiple-model iterative
- RHA
  - preference analysis: multiple models
- J- and T-Linkage
  - preference analysis, clustering: multiple models

Parametric methods

- Hough Transform
  - voting: single model
- Generalized Hough Transform
  - voting, template matching: single model
- Randomized Hough Transform
  - RANSAC-like: multiple models

Notion of Hough Transform (HT)

- Detection of given shapes and curves
- Shapes or curves defined **analytically**
  - straight line
  - circle, ellipse, etc.
- Shapes or curves defined **by sample pattern**
  - arbitrary smooth shape or curve
  - fixed orientation and scale

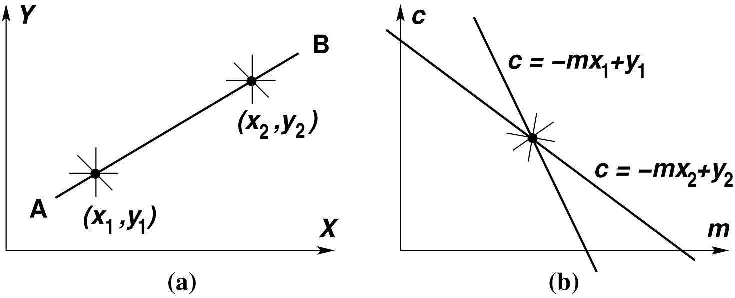
Original Hough Transform

- **Paul Hough**
  - worked on track detection of particles in bubble chamber
  - in 1962, obtained USA pattent for transform
- Applicable to parameterized **straight lines**
- Voting procedure
  - points vote for straight lines crossing them
- Image space $\longrightarrow$ parameter space (accumulator array)
- Clustering in parameter space $\longrightarrow$ straight lines
  - without endpoints

Modifications of Hough Transform

- Use of edge orientations
- More complex shapes and curves
  - e.g., non-analytically defined shapes
- Joint handling of different shapes
- Optimal resolution of parameter space
- Multiresolution procedures

Straight line in image and parameter spaces



(a) Equation of line in **image space**: $y = mx + c$

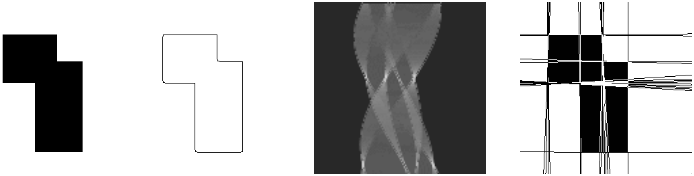
(b) Equation in **parameter space**: $c = -mx + y$

- voting: point in Image sp. $\longrightarrow$ straight line in Parameter sp.

$\rightarrow$ generate line in accumulator, increment counters (cells)

- line AB in I-space $\longrightarrow$ crossing of two lines in P-space

Simple example of detection in polar coordinates



input image　　edges　　accumulator (θ, r)　　result[1]

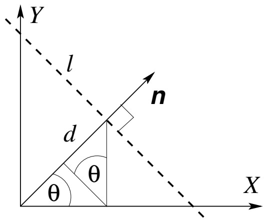
- $y = mx + c$ not really good: $m, c \in [-\infty, \infty]$
- Polar coordinate version: $r = x \cos\theta + y \sin\theta$
  - variables in finite domains $\longrightarrow$ discrete accumulator array
  - sinusoids instead of straight lines
- Processing of filled accumulator array
  - local maxima above lower limit (threshold parameter)
  - $\rightarrow$ fantom lines possible

[1] Source: homepages.inf.ed.ac.uk/rbf/HIPR2/hough.htm

Using edge orientation

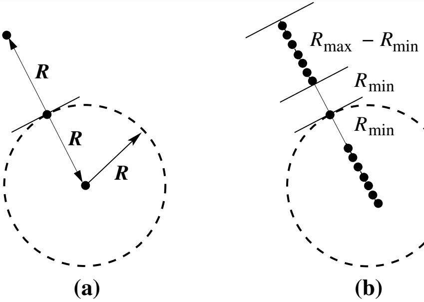
Parameterization of straight line l:

- θ: angle of normal $\mathbf{n}$ ($\|\mathbf{n}\| = 1$)
- d: distance to line



- In edge map, (x, y): edge position, θ: gradient direction
- Every small segment of line votes for **point** in space θ, d
  - $\rightarrow$ every edge votes for point in accumulator
  - $\theta = \arctan n_y / n_x, \quad d = x n_x + y n_y$
- Number of operations decreases drastically, but:
  - inaccuracy of edge angle must be taken into account
  - $\rightarrow$ for large d, no distinct cluster in accumulator

Circle detection using edges

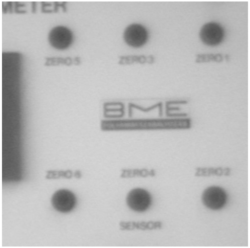


(a) Given radius
- increment two cells in accumulator
- imprecise edge direction $\longrightarrow$ indistinct cell cluster

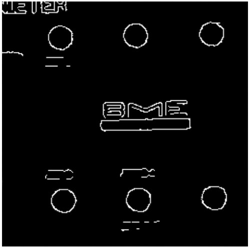
(b) Radii in range $[R_{min}, R_{max}]$
- increment cells on two symmetric segments of straight line
- length of generated segments: $R_{max} - R_{min}$

Outline

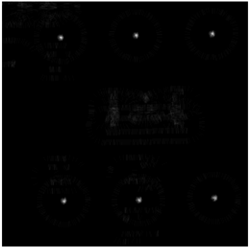
Regular circles 1/2



input image



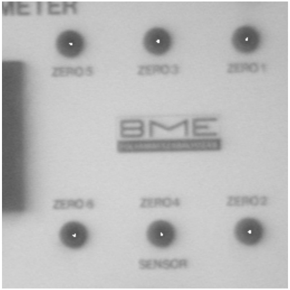
edge map



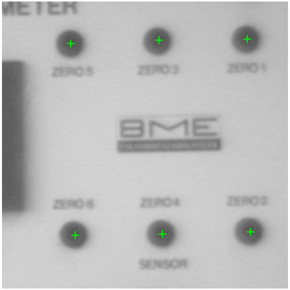
accumulator image

- Edge detection: 7×7-es Canny operator
  $\rightarrow$ directions of edge normals
- Processed, normalized accumulator image
  - maximum value $\longrightarrow$ 255

Regular circles 2/2



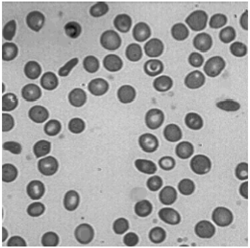
centers of circles

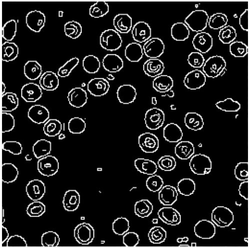


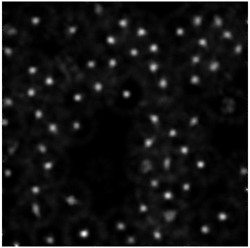
dark blobs

- Centers of circles: binarized (Otsu), thinned accumulator
- Blob detection in scale-space (size: 30 – 35 pixels)
- Hough-positions are more precise (?)

Blood cells 1/2

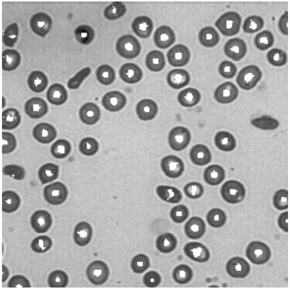

input image


edge map

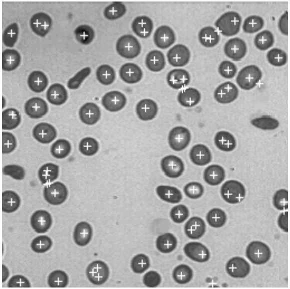

accumulator image

- Edge detection: 7×7-es Canny operator
- Processed, normalized accumulator image
  - smoothing by 5×5 box filter
  - maximum value $\longrightarrow$ 255

Blood cells 2/2



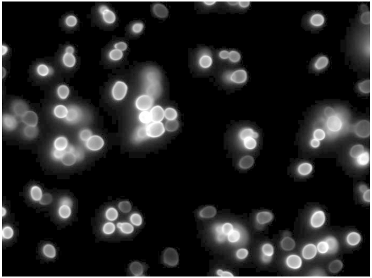
centers of circles



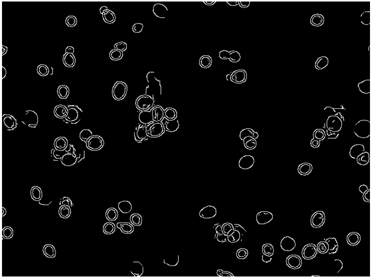
dark blobs

- Right: size-invariant blob detection in scale-space
  - similar results
- Many cells are rather ellipses than circles
  - $\rightarrow$ imprecise, blurred centers

Cells 1/2



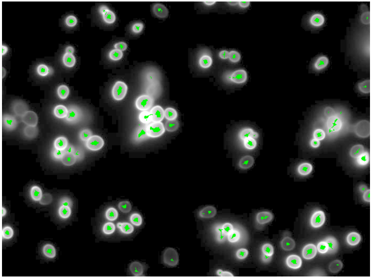
input image



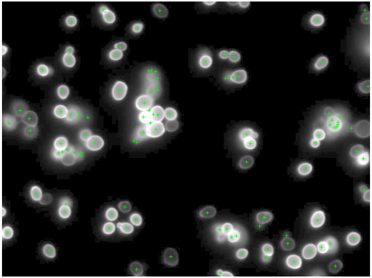
edge map

- Low contrast in some cells $\longrightarrow$ missing contours
  $\rightarrow$ lower accumulator value $\longrightarrow$ noise sensitivity
- Light cell borders $\longrightarrow$ double contours
  - does not cause problem

Cells 2/2



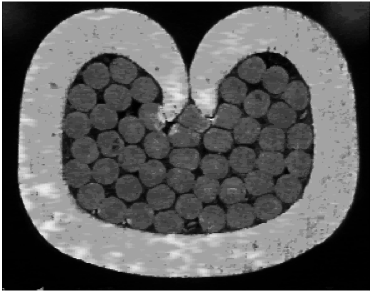
centers of circles



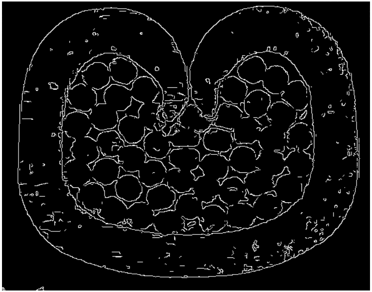
light blobs

- Many cells are rather ellipses than circles
  $\rightarrow$ imprecise, blurred centers
- Right: size-invariant light blob detection
  - more precise, more cells found
  - but more false detections (?)

Cable cross-section 1/2



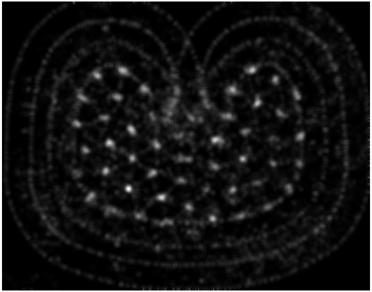
input image



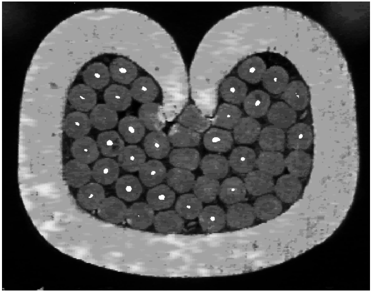
edge map

- Low contrast $\longrightarrow$ missing contours
- Cabel components are deformed circles
  $\rightarrow$ noise sensitivity, imprecision

Cable cross-section 2/2



accumulator image



centers of circles

- Many cable components lost
  - increase detectioni rate (low threshold) $\longrightarrow$ false detections
- Blob detector **not applicable** here
  - touching components
  - no background around them

Directions of development

- Handling more complex shapes and curves
  - curves not specified analitically

  $\rightarrow$ **Generalized Hough Transform**
- Joint handling of different shapes

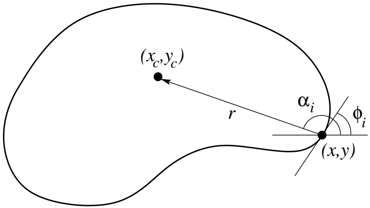
  $\rightarrow$ **Randomized Hough transform**
- Optimal resolution of accumulator array

  $\rightarrow$ multiresolution procedures

Operation principles of Generalized HT (GHT) 1/2

R-table

measured ϕ_k	radii $\mathbf{r}^k$
ϕ_1	$\mathbf{r}_1^1, \mathbf{r}_2^1, \ldots, \mathbf{r}_{N_1}^1$
ϕ_2	$\mathbf{r}_1^2, \mathbf{r}_2^2, \ldots, \mathbf{r}_{N_2}^2$
...	...
ϕ_m	$\mathbf{r}_1^m, \mathbf{r}_2^m, \ldots, \mathbf{r}_{N_m}^2$



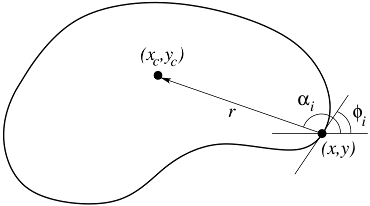
Step 1. Scan template shape and form ***R*-table**

- Select reference point (x_c, y_c) within template shape
  - e.g., centroid
- Possibly, several radii $\mathbf{r} = (r, \alpha)$ for same edge direction ϕ_k
  - in different points of shape

Operation principles of Generalized HT (GHT) 2/2

R-table

measured ϕ_k	radii $\mathbf{r}^k$
ϕ_1	$\mathbf{r}_1^1, \mathbf{r}_2^1, \ldots, \mathbf{r}_{N_1}^1$
ϕ_2	$\mathbf{r}_1^2, \mathbf{r}_2^2, \ldots, \mathbf{r}_{N_2}^2$
...	...
ϕ_m	$\mathbf{r}_1^m, \mathbf{r}_2^m, \ldots, \mathbf{r}_{N_m}^2$



Step 2. Search for given shape in input edge map

- In edge point (x, y) with direction ϕ_k:
- Fill **reference point accumulator** for every $\mathbf{r}^k$
  - $x_c = x + r(\phi_k)\cos(\alpha(\phi_k))$, $y_c = y + r(\phi_k)\sin(\alpha(\phi_k))$

Randomized HT: Hough meets RANSAC

- RANSAC: **RANdom SAmple Consensus**
- Both RHT and RANSAC: for parameterized curves
- Randomly select points in number needed to estimate model
  - → e.g., two points for straight line
- Number of points can be decreased by edge direction data
  - → e.g., for ellipse: 3 points with edge directions
- Use selected points to vote for model in parameter array

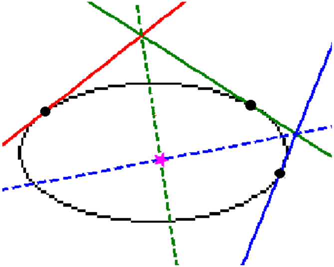
RHT for straight lines

- Parameter array: vector m, c plus counter n
- Map $x_i, y_i \longrightarrow m_i, c_i$
- Merge m_i, c_i with previous m_k, c_k, n_k, $k < i$

  $\rightarrow$ if distance between m_i, c_i and $m_k, c_k < \delta$,
  $\rightarrow$ then $n_k \leftarrow n_k + 1$

- If cannot merge, open new cell: m_i, c_i and $n_i = 0$
- Efficient data structure needed for search in parameter array

RHT for ellipse with known edge directions



- Three contour points with tangent directions
- Each bisector points at center
- Two bisectors meet in center, or close to it
  - → calculate crossing point and **vote for center**

Outline

Advantages of HT

- Robustness to outliers
- Robustness to missing, noisy data
- Efficient use of edge directions
- Shapes specified analytically or by sample
- Joint handling of different models
- RHT: variable resolution of parameter space
  $\rightarrow$ faster voting

Disadvantages of HT

- Images with dense points or edges can pose problems
  - random configuration detected as shape or curve
- More parameters $\longrightarrow$ more computation, less robust
- Joint use of edge directions $\longrightarrow$ less precise
- In practice, HT is mainly used for straight lines and circles
- Pseudo outliers can pose problems
  - e.g., low curvature curves in case of straight lines
- Setting optimal resolution of parameter space is not easy