Implementation of Contracting Curve Density Algorithm for Applications in Personal Robotics

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Outline

Motivation

Some challenging task in personal robotics

- Image segmentation
- Pose estimation
- Object recognition and tracking

- Model-based methods: these problems require much information external to the image
- Curve-fitting process: a crucial part of these problems

Requirements

- Robustness: stable in texture, clutter, poor contrast environment
- Accuracy: high sub-pixel accuracy
- Efficiency: time-constrained, limited computer hardware resources in personal robotics

How the original CCD works?

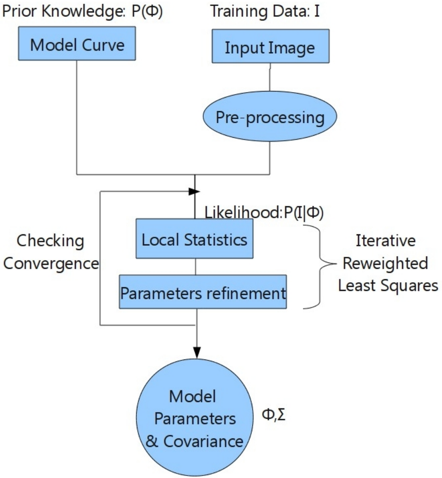


Figure: the CCD algorithm

Sketch of the CCD algorithm

Basic steps of the CCD algorithm

- Contour initialization
- Learning of local statistics
- Refinement of model parameters

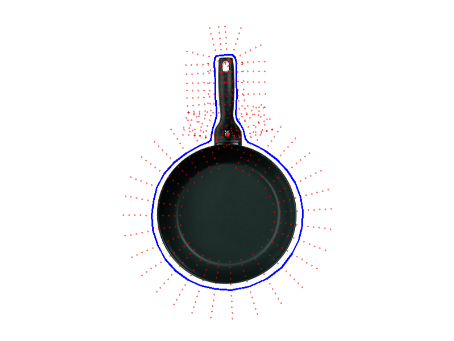


Figure: The contour of a pan

An alternative view of the CCD algorithm

Probit regression

- Evaluation of conditional distribution $p(\Phi|\mathbf{I})$

$$p(\Phi|\mathbf{I}) \propto \underbrace{p(\mathbf{I}|\mathbf{m}_\Phi, \Sigma_\Phi)}_{\text{local statistics}} \quad \times \quad \underbrace{p(\Phi)}_{\text{prior distribution}}$$

  Local statistics, namely the likelihood, is a probit function with respect to Φ

- Goal: MAP (maximum a posteriori probability) solution of cost function $\mathcal{Q}(\Phi)$

$$\mathcal{Q}(\Phi) = \arg\max_{\Phi} \ln(p(\Phi|\mathbf{I}))$$

  Approach: iterative reweighted least squares (IRLS) e.g. Gaussian Newton method, SVM

An alternative view of the CCD algorithm

A classification problem

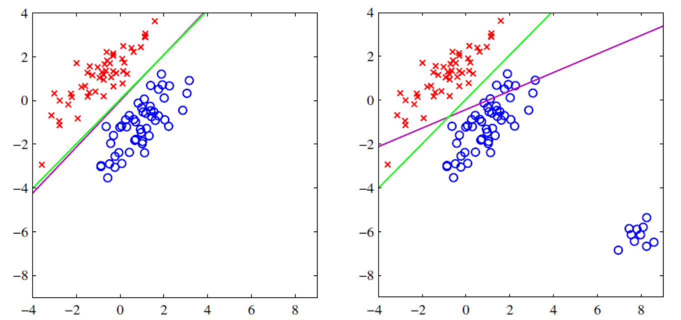


Figure: A classification problem

3-4 papers

Quadratic and Cubic B-spline curves

B-spline curves

$$\mathbf{C}(u) = \sum_{i=0}^{m-n-2} P_i B_{i,n}(u) \; , \; u \in [u_n, u_{m-n-1}]$$

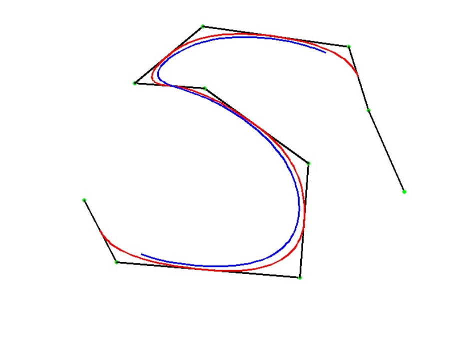


Figure: B-spline curves of degree = 1, 2, 3

Logitic and Probit function

Logistic function

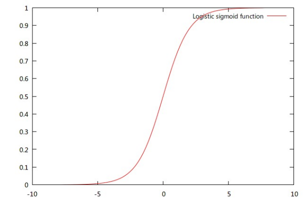


Figure: Logistic function

$$f(\cdot) = \frac{1}{1 + \mathrm{e}^{-x}}$$

Logitic and Probit function

Logistic function

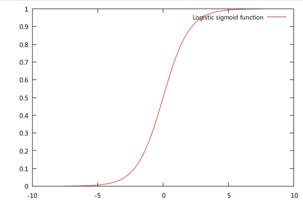


Figure: Logistic function

$$f(\cdot) = \frac{1}{1+\mathrm{e}^{-x}}$$

Probit function

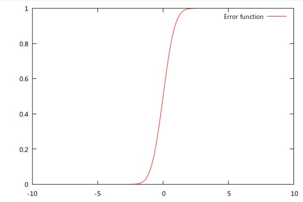


Figure: Probit function

$$f(\cdot) = \frac{1}{2}(\frac{1}{\sqrt{2}} erf(x) + 1)$$

Three-dimensional Affine Shape-space

Parallax effect in two-dimensional affine shape-space

Figure: Parallax effect

Three-dimensional affine shape-space

Figure: Three-dimensional affine shape-space

Initialization from SIFT Features

Initialization from SIFT Features

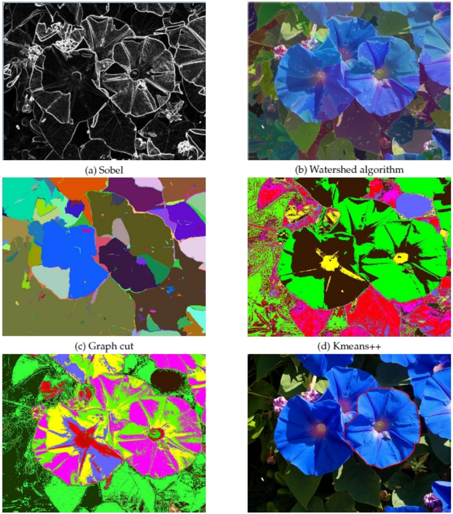
Figure: Initialization from SIFT Features

Contracting Curve Density (CCD) Tracker Algorithm

Algorithm 1 Contracting Curve Density (CCD) tracker

$\Phi \leftarrow 0$
$\mathbf{C} \leftarrow$ *contour_initialization*()
while *NewFrame* **do**
    $\mathbf{I} \leftarrow$ *pre_processing*()
    $\mathbf{C} \leftarrow$ *contour_distortion*(Φ)
    $\Sigma \leftarrow$ *covariance_initialization*()
    $\Phi \leftarrow \Phi^{\mathrm{old}}$
    while *convergence* $=$ *FALSE* **do**
        local_statistics_learning()
        cost_function_MAP()
    end while
    $\Phi \leftarrow \Phi_{MAP}$
    $\Sigma \leftarrow \Sigma_{MAP}$
end while

Segmentation



(a) Sobel (b) Watershed algorithm

(c) Graph cut (d) Kmeans++

(e) Expectation and Maximization (f) CCD

Figure: A Comparison of Image Segmentation Algorithms

Manual initialization

Shadow effects

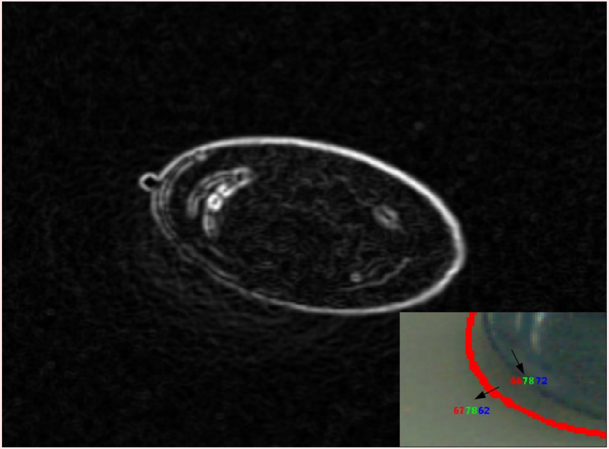


Figure: Shadow effects

Initialization from SIFT Features

Tracking initiated from SIFT features

- Match SIFT keypoints between the template image and the test image
- Discard the false matching points using the RANSAC algorithm
- Compute the homography
- Transform the contour of the template image onto the test image
- Apply the CCD tracker to the video

Summary

Investigate and implement the CCD approach

- Based on the OpenCV library
- A ros-package
- Released under open source BSD license

Improvements

- B-spline curve and three-dimensional affine shape-space
- Logistic regression and sofmax regression
- Automated contour initialization methods: SIFT features and point clouds

Future work

Future work

- Use statistics based on other image features instead of the RGB statistics
- Integration of the CCD algorithm into a more complex tracking framework (e.g. the Lucas-Kanade method (LKM), the extended Kalman filter (EKF))
- Port to Android system to support mobile applications
- ....