A Highly Accurate Level Set Approach for Segmenting Green Microalgae Images

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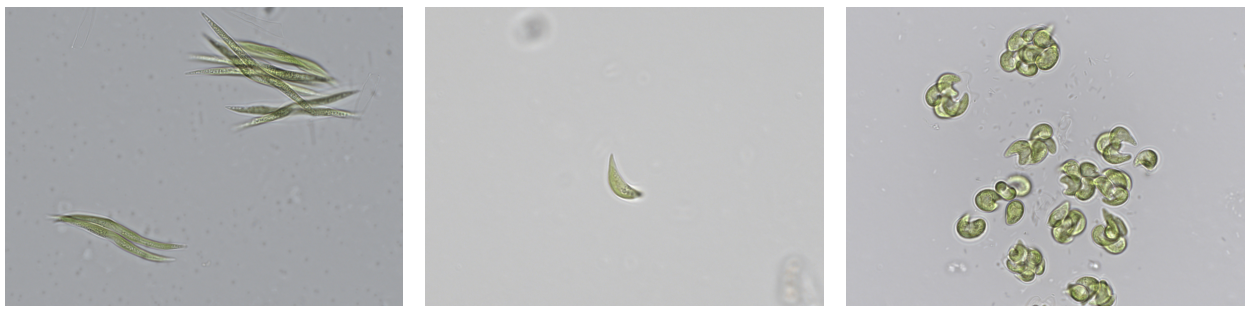
Outline

- Introduction and motivation
- Segmentation and the level set method
- Proposed segmentation method
- Experimental results
- Conclusion and future work

Introduction

- Green microalgae (algae) play an important role in nature and human life
- Taxonomical classification of green algae is a hard and complex task



Introduction

- Overall idea: Devise a semi-supervised classification approach supported by a visual analytics process

- **Goal:** obtain representative and accurate algae shapes for morphological feature extraction

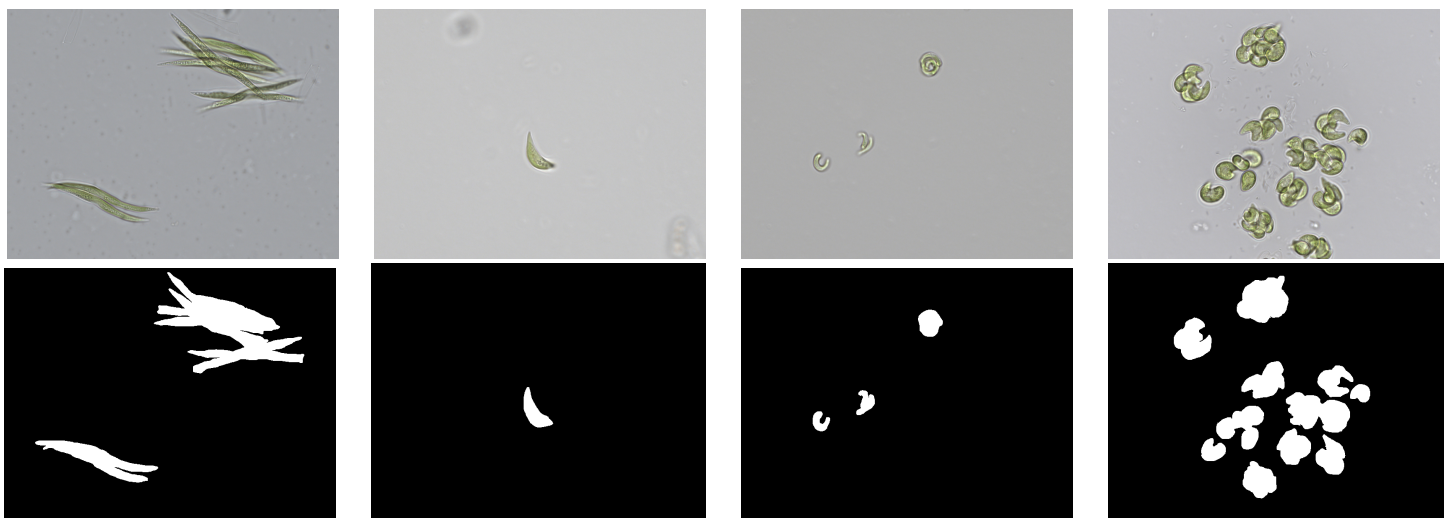
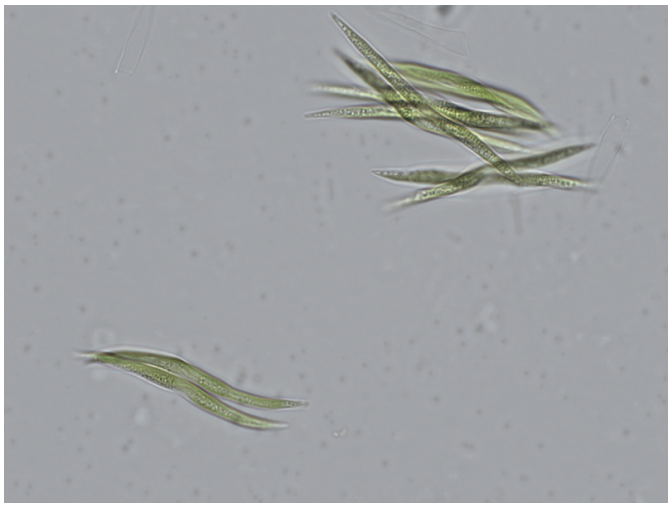


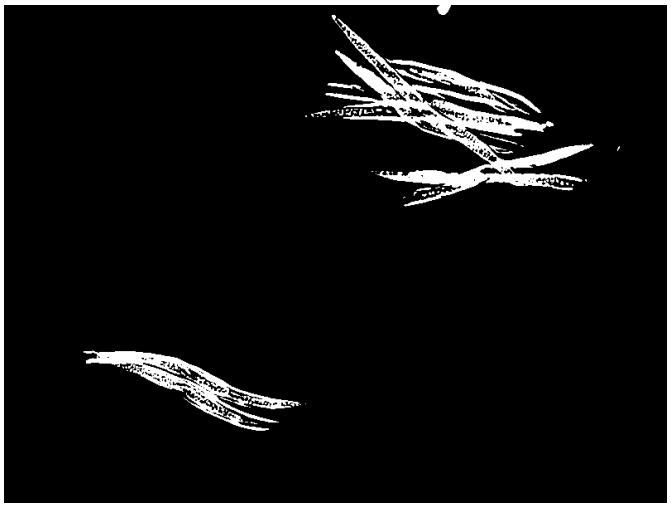
Image Segmentation: Assumptions

- Goal: subdivide an image in its constitutent regions
- Let $\Omega \subset \mathbb{R}^2$ be the image domain
- Function $I : \Omega \rightarrow \mathbb{R}^3$ is the digital RGB image
  1. the regions of interest (Ω_1) : algae cells
  2. the background ($\Omega \backslash \Omega_1$): fluid

Motivation

- Binarization using Otsu's threshold [1]

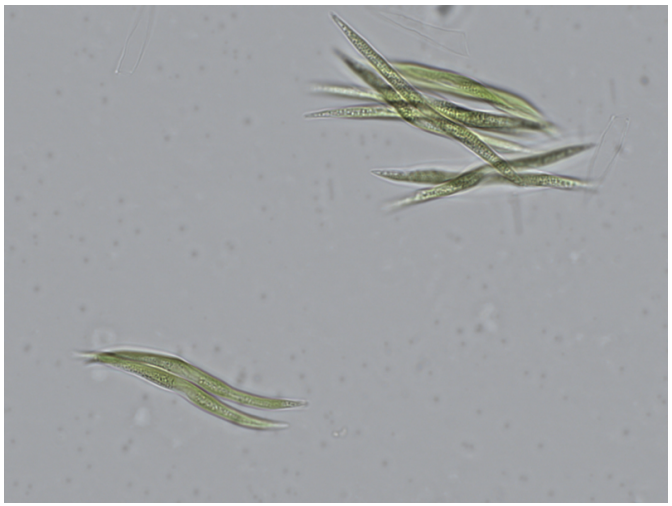




[1] OTSU, Nobuyuki. A threshold selection method from gray-level histograms. Automatica, v. 11, n. 285-296, p. 23-27, 1975.

Motivation

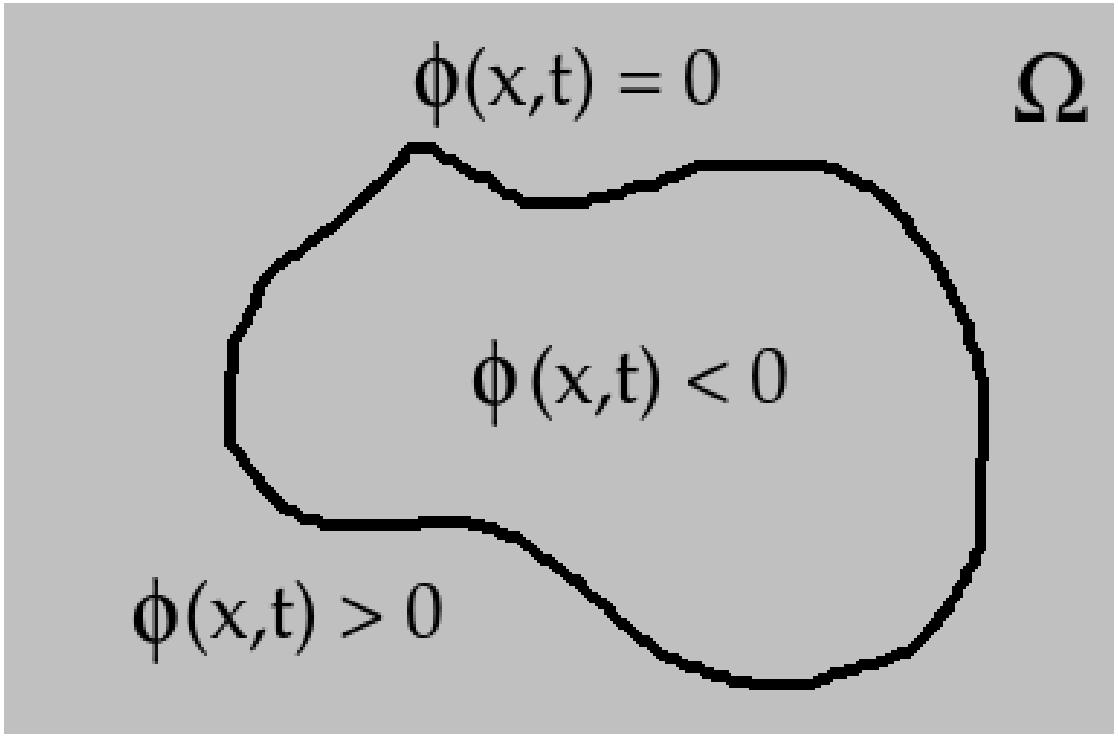
- Canny edge detector [2]



[2] CANNY, John. A computational approach to edge detection. IEEE Transactions on Pattern Analysis and Machine Intelligence, n. 6, p. 679-698, 1986

Level set method

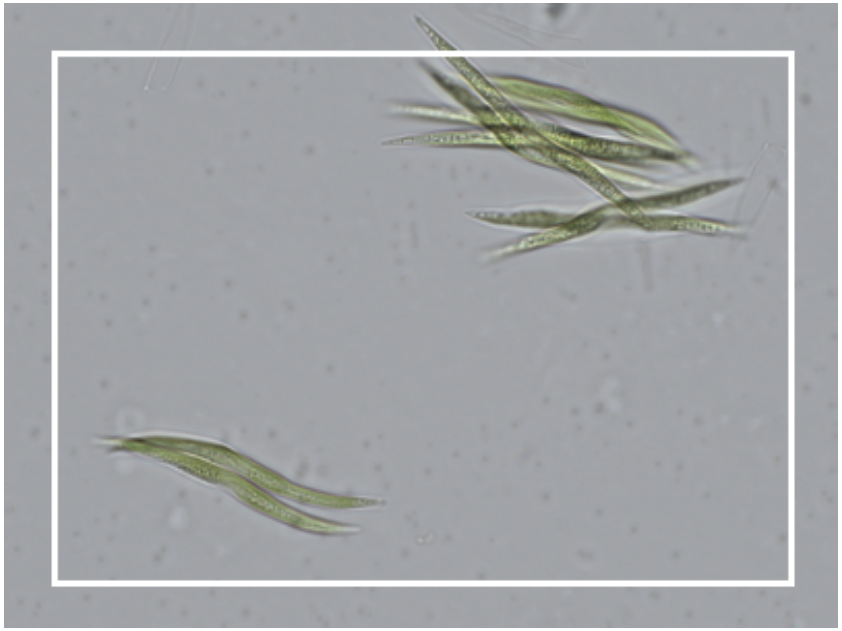
- The dynamic curve is defined by a *Lipschitz* function $\phi : \Omega \times [0, \infty) \to \mathbb{R}$



Level set method

- Curve evolves according to the level set equation:

$$\frac{\partial \phi}{\partial t} + F|\nabla \phi| = 0 \tag{1}$$



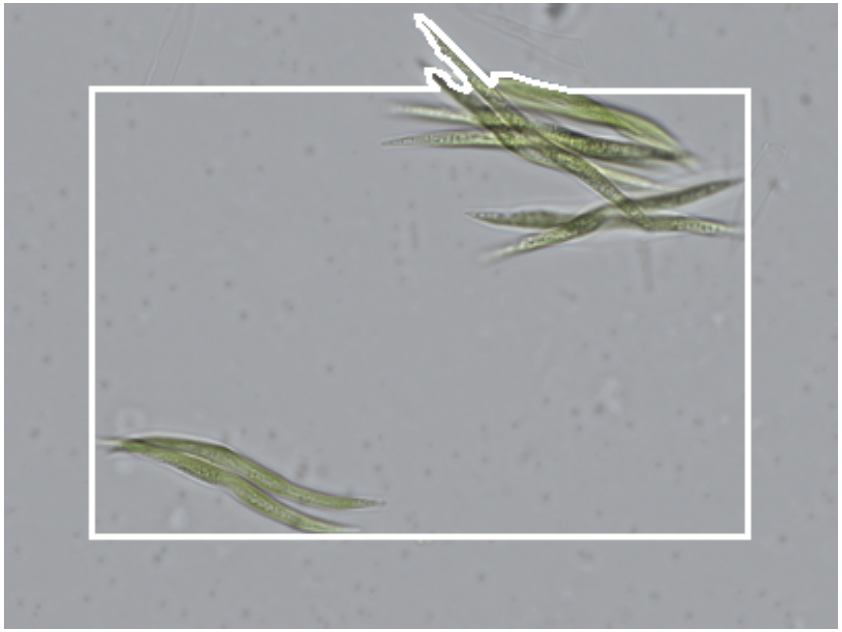
Level set method

- Curve evolves according to the level set equation:

$$\frac{\partial \phi}{\partial t} + F|\nabla \phi| = 0$$

Level set method

- Speed term F incorporate image properties to stop the curve evolution

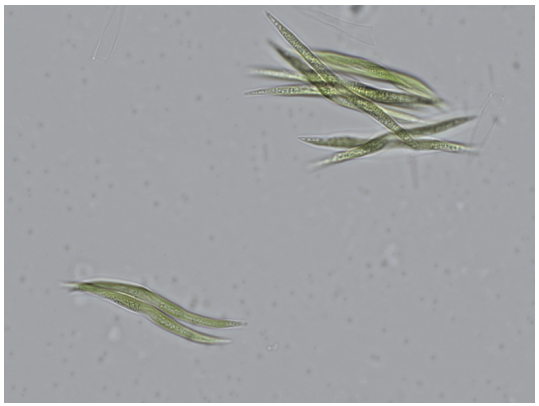


Level set method

- Highly sensitive to initial conditions
  1. Level set is optimized in a non-convex space
- Numerical instability
  1. Re-initialization of level set curve periodically

Chan-Vese model

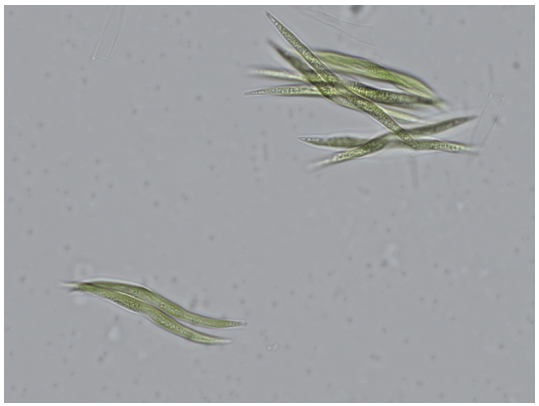
- Chan-Vese model uses a level set to segment images [3]
  1. Image regions are represented by constants
  2. Sensitive to initial conditions



[3] CHAN, Tony F. et al. Active contours without edges. IEEE transactions on Image processing, v. 10, n. 2, p. 266-277, 2001.

Rousson-Deriche's model

- Rousson-Deriche's model also employs the level set [4]
  1. Image regions are represented by probability distributions
  2. Time consuming: re-estimation of parameters periodically



[4] CREMERS, Daniel; ROUSSON, Mikael; DERICHE, Rachid. A review of statistical approaches to level set segmentation: integrating color, texture, motion and shape. International journal of computer vision, v. 72, n. 2, p. 195-215, 2007.

Proposed method

- Follow Rousson-Deriche's approach for representing image regions
- Estimate region parameters prior to the functional's minimization
  1. Only optimize the level set function
- Include a boundary potential function g in Rousson-Deriche's functional
  1. Reduce the diffusion process in boundary neighborhood

$$g(|\nabla I|) = \frac{1}{1 + \beta |\nabla I|^2} \tag{2}$$

Proposed method

- Minimization problem is defined as

$$\min_{\phi} \Bigg\{ F_{PM}(\phi, \{\theta_1, \theta_2\}) = \int_{\Omega} g|\nabla H(\phi)| - \lambda \int_{\Omega} H(\phi(\mathbf{x})) \log(P_1(I(\mathbf{x})|\theta_1)) d\mathbf{x} - \lambda \int_{\Omega} (1 - H(\phi(\mathbf{x}))) \log(P_2(I(\mathbf{x})|\theta_2)) d\mathbf{x} \Bigg\}. \quad (3)$$

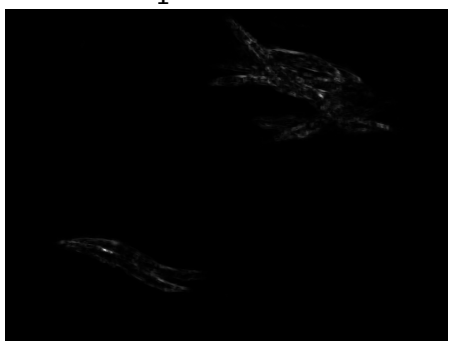
- Keep $\{\theta_1, \theta_2\}$ fixed during the functional's minimization

Estimation of distribution parameters

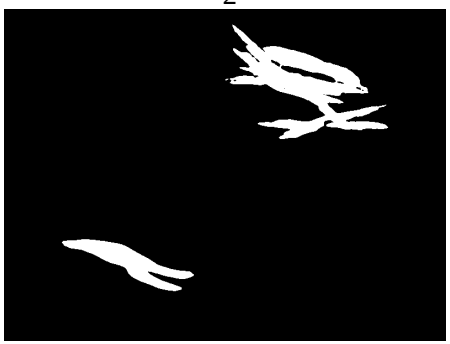
- Obtain automatically a binary mask based on computed eigenvalues $\{\lambda_1, \lambda_2, \lambda_3\}$ of the RGB image I
- The image related to the third eigenvalue $I_{\lambda_3}(x, y)$ was selected

$I_{\lambda_1}(x, y)$

$I_{\lambda_2}(x, y)$



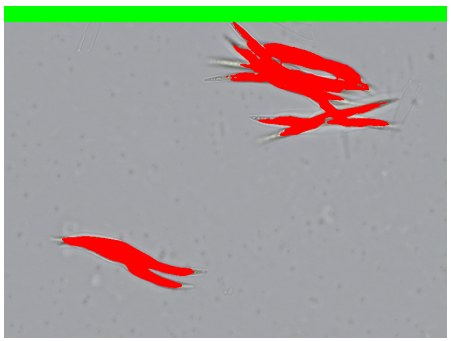
$I_{\lambda_3}(x, y)$

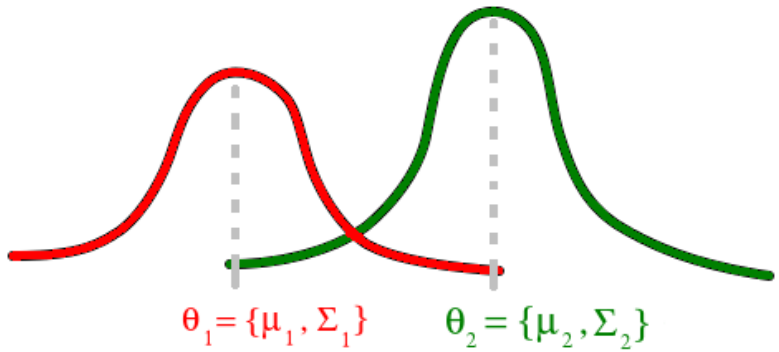


binary mask after thresholding

Estimation of distribution parameters

- The distributions are assumed to be multivariate Gaussians
- Use the mask to sample intensities of image regions and compute the parameters (mean and covariance matrix)





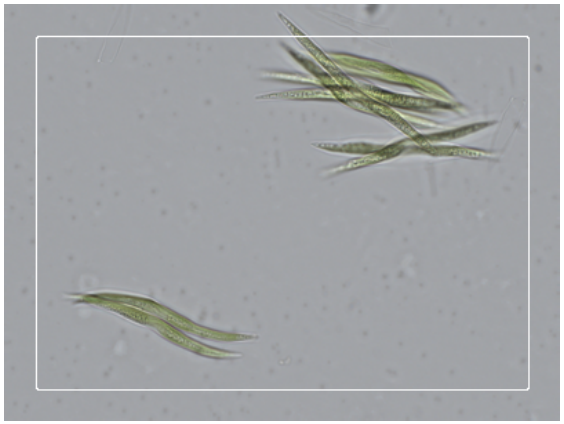
Algorithm

1. Estimate the distribution parameters θ_1 and θ_2 associated with the image regions;
2. Solve numerically the Partial Differential Equation below:

$$\frac{\partial \phi}{\partial t} = div\left(g\frac{\nabla \phi}{|\nabla \phi|}\right) + \lambda \log(P_2/P_1) \tag{4}$$

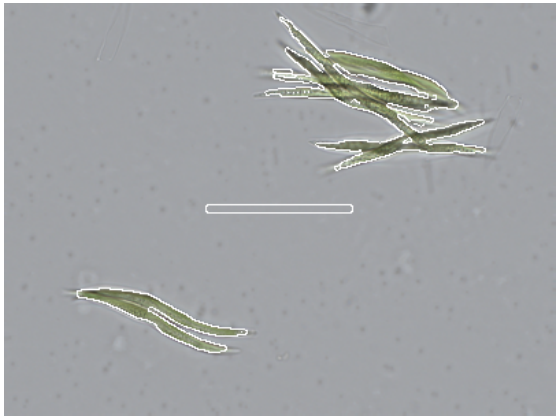
3. Threshold the final ϕ obtaining a binary image b
4. Perform a dilation morphological operation on b

Illustrative example

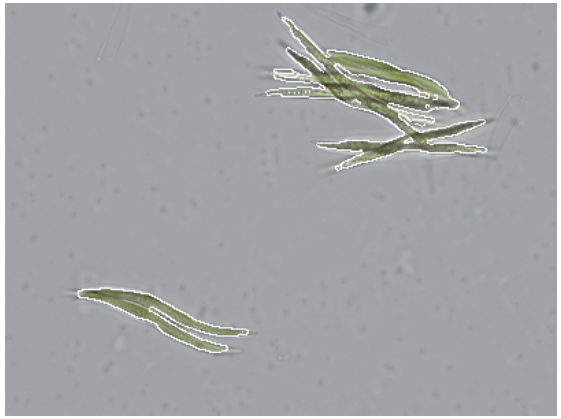


Iteration 2

Iteration 400



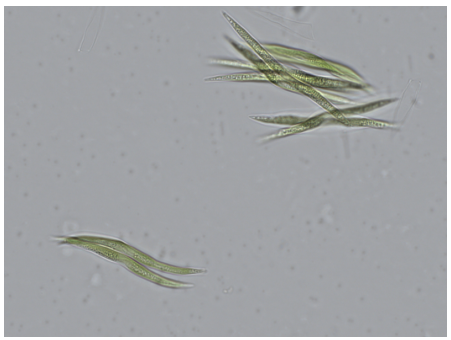
Iteration 980



Iteration 1480

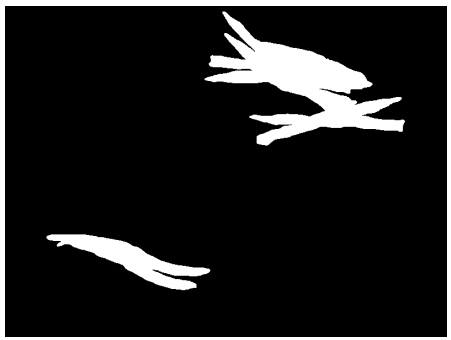
Green algae segmentation example

- Accuracy of 0.974



Original image

Final segmentation



Ground-truth

Experimental results

- We used a set composed by 44 images of green algae of the *Selenestraceae* families
- Biologists provided the ground-truth (manual segmentation) for comparison purposes
- Compute the accuracy for each image:

$$Acc = \frac{TP + TN}{TP + TN + FP + FN}, \tag{5}$$

1. True-Positive (TP) pixels
2. False-Positive (FP) pixels
3. True-Negative (TN) pixels
4. False-Negative (FN) pixels

Experimental results

Segmentation techniques	accuracy	std
1. Proposed Method	**0.962**	**0.009**
2. Conventional level set [1]	0.938	0.0116
3. *Rousson and Deriche*'s	0.951	0.0209

[1] OSHER, Stanley; SETHIAN, James A. Fronts propagating with curvature-dependent speed: algorithms based on Hamilton-Jacobi formulations. Journal of computational physics, v. 79, n. 1, p. 12-49, 1988.

Analysis

- The proposed method is less sensitive regardless to the curve initial positioning
- Accurate segmentation: shape contours are better preserved than similar approaches
- It performs regularly well due to the low standard deviation of accuracy rates
- Drawback: time consuming approach

Conclusion and future work

- We proposed a level set approach for segmenting green algae images, which represents the image regions by Gaussian distributions
- A technique for automatic sampling of image regions was presented to support the estimation of Gaussian parameters
- Experimental results indicate higher accuracy of the proposed method as compared with similar approaches in literature
- Apply our method to other biological image processing problems with similar characteristics

Thanks for your attention

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