Stromule Branch Tip Detection Based on Accurate Cell Image Segmentation

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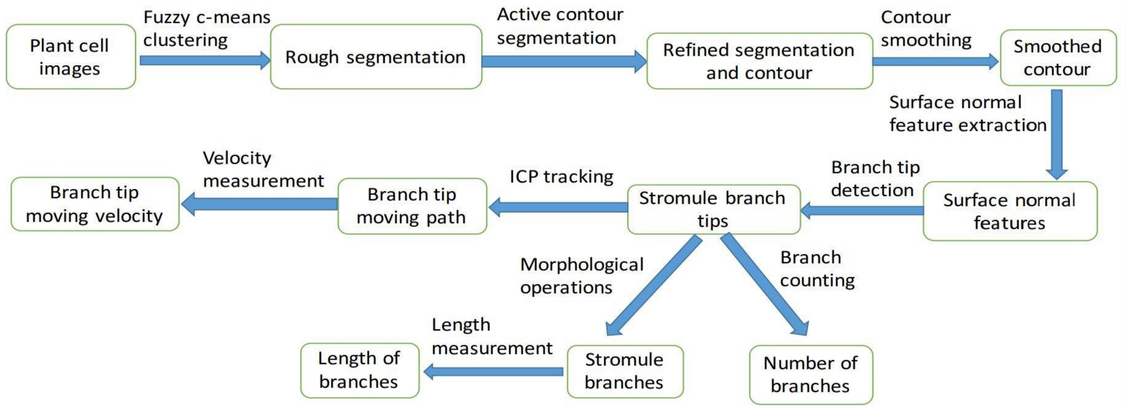
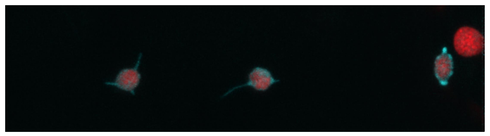
Contribution:

- We propose a complete system to conduct stromule segmentation, detection and tracking
- We design our furface normal feature to accurately detect the stromule branch tips
- In each component of the system, we modify the classic algorithms according to our problem to make the system better fit the stromule analysis task
- Our system can conduct the stromule segmentation task based on both a single image and images from different depth in a stack

Overview:



Stromule Segmentation:



Original image

Fuzzy C-means Segmentation:

- fuzzy c-means (FCM) clustering assigns pixels to each category with fuzzy coefficients, which is the probability that the pixel belongs to the cluster.
- Pixels in the same cluster tend to have similar color.
- Pixels closing to each other in the spatial domain are more likely to belong to the same cluster.
- Spatial information is considered together with the spectral information in clustering.

Fuzzy C-means clustering

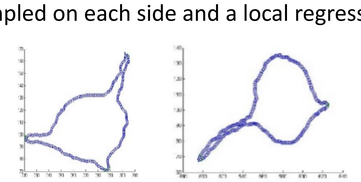
Active Shape Contour Segmentation:

- Energy-minimizing spline forced by both internal and external constraint.
- Internal constrains include stretch and curvature, which is optimized by gradient descent method to move the contour.
- External constrains contain image forces and user defined constraint
- Substitute user defined constraint by rough segmentation
- Automatic segmentation without pre-defined initial contour, largely saving manual efforts.

Active contour segmentation

Contour Smoothing:

- Project all the contour points onto the local regression line
- Apply a sliding window along the contour points
- For each point, N neighboring points (total 2N+1 points) in the window are sampled on each side and a local regression line is estimated.



Boundary extraction and smoothing

Segmentation Based On Image Stack:

- A specific focal length can only capture a part of the cells clearly because the cell is located in different depth
- Capture a series of microscopy images with different focal length (z stack)
- Combine the segmentation result on z stack images

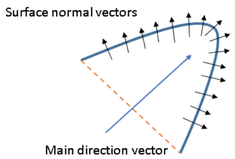
A series of cell images on z stack

Correspondingly, the segmentation result for each image

The combination of the image segmentation result on z stack

Stromule Branch Tip Detection And Tracking:

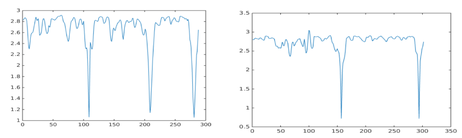
Surface Normal Feature:



- Keep a window size 15 points along the boundary.
- For each point, a normal is calculated based on its adjacent points (small arrows)
- Calculate a main direction for the whole window (the big arrow), perpendicular to the connection line of the starting point and ending point (orange line)
- Each point's normal is projected to the main direction of the window, resulting in a projection distance along the main direction.
- A 15 dimensional vector with each dimension representing a projection distance is used as the feature of the window.

Stromule Tip Detection:

- Pre-define Gaussian distribution with pre-learned parameters as the ideal feature
- For a new shape captured by the sliding window, we measure the distance between the feature extracted from the shape and our ideal feature.
- We detect the branch by setting a threshold for the distance.



The distance histogram of all the window features to the pre-learned Gaussian curve feature.

Tip detection result based on the distance to pre-learned Gaussian curve feature

Stromule Branch Detection:

- Apply image opening on the foreground images, removing the major body (non-branch area) of the cells
- Match the branch tip detection result to the image opening result, which further removes all the non-branch pixels left by the image opening operation.

Left: Segmented cell; right: Detected cell branches.

Stromule Tracking:

- Tracking tip based on Iterative Closest Point Mean Square Error (ICP MSE)
- Combine the Euclidean distance of both points' position coordinates and their surface normals in ICP tracking.

ICP tracking for 8 frames