LIVING MACHINES 2020



An Image-based Method for the Morphological Analysis of Tendrils with 2D Piece-wise Clothoid Approximation Model

Jie Fan [1, 2], Francesco Visentin [1], Emanuela Del Dottore [1], Barbara Mazzolai [1]

[1] *Istituto Italiano di Tecnologia – Center for Micro-BioRobotics@SSSA, Pontedera, Italy*

[2] *The BioRobotics Institute, Scuola Superiore Sant'Anna, Pontedera, Italy*

THE BIOROBOTICS INSTITUTE

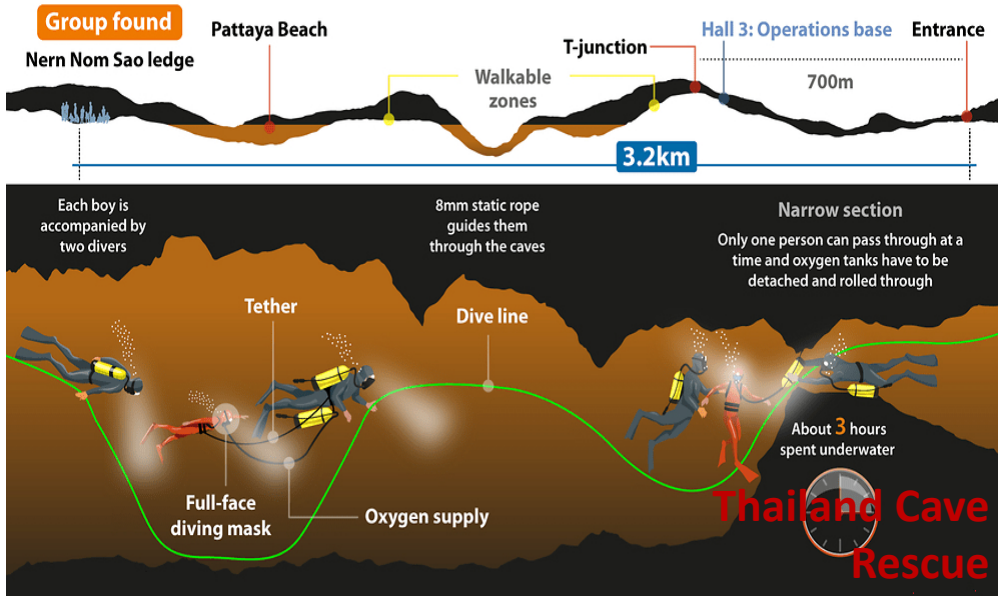
Sant'Anna School of Advanced Studies – Pisa

iit BSR ISTITUTO ITALIANO DI TECNOLOGIA

GROW BOT

Motivation

Exploration of unstructured environment difficult to reach by human beings



- Filiform structure
- Moving by growing
- Anchorable

- Thin body
- Work on long distance
- Adaptable



Proposed Method

Correctly describe and analyze the morphology of filiform structures

Linear property allows a smooth transition of curvatures

$$\mathcal{K}(s) = k_1 s + k_2 \longrightarrow \text{clothoid}$$

$$k_1 = 0 \longrightarrow \text{circle}$$

$$k_1 = k_2 = 0 \longrightarrow \text{straight line}$$



Passionflower tendril



Clothoid curve

Proposed Method

Correctly describe and analyze the morphology of filiform structures

Linear property allows a smooth transition of curvatures

$$\mathcal{K}(s) = k_1 s + k_2 \longrightarrow \text{clothoid}$$

$$k_1 = 0 \longrightarrow \text{circle}$$

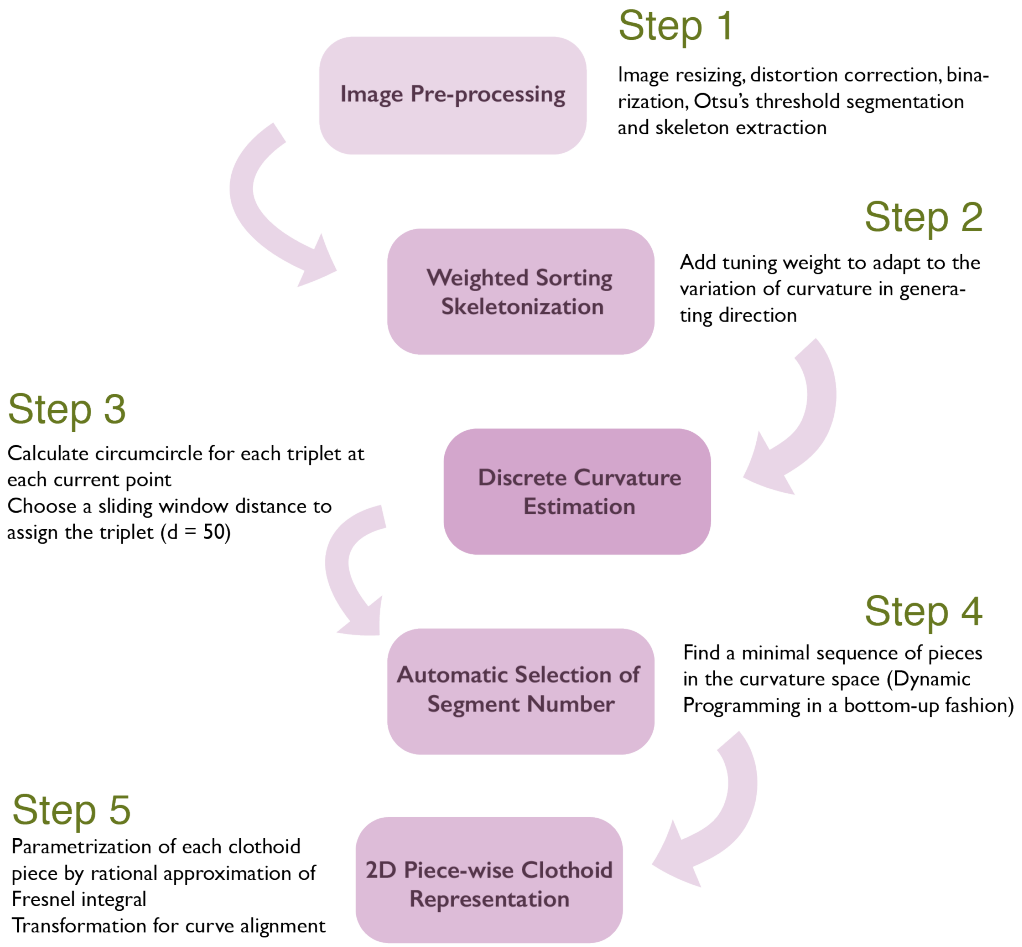
$$k_1 = k_2 = 0 \longrightarrow \text{straight line}$$



Passionflower tendril



Clothoid curve

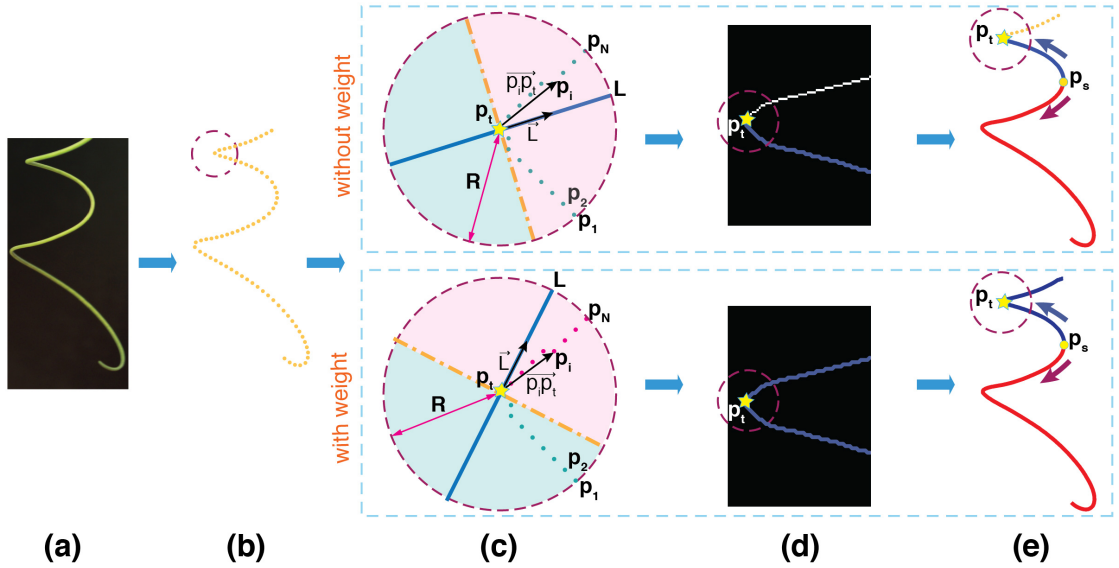


Flowchart of methodology

Proposed Method

Weighted Moving Least Squares Method – Step 2

(based on the previous work [Jie Fan et al. Robosoft 2020])

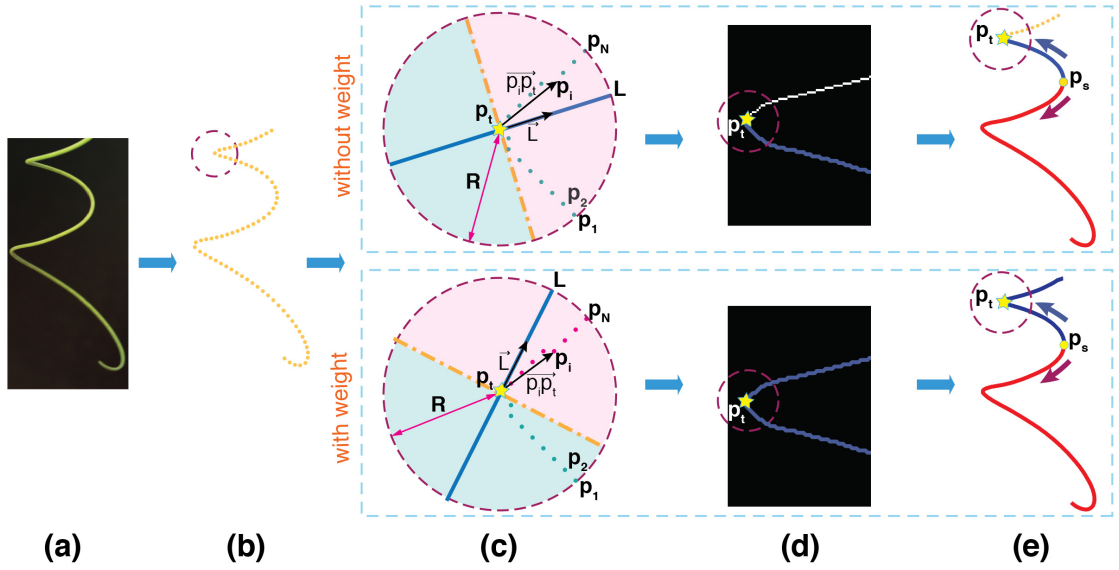


Original tendril Skeletonization The comparison of sorting results

Proposed Method

Weighted Moving Least Squares Method – Step 2

(based on the previous work [Jie Fan et al. Robosoft 2020])



(a) Original tendril (b) Skeletonization (c) The comparison of sorting results (d) (e)

Automatic Selection of Segment Number – Step 4

Dynamic Programming with an Up-sweep Approach

$$\mathcal{J}(p_i, p_j) = \min_{i<k<j} \{\mathcal{J}(p_i, p_k) + \mathcal{J}(p_k, p_j), \epsilon + \mathcal{E}_{fit}(p_i, p_j)\}$$

penalty to generate a single segment

slope intercept

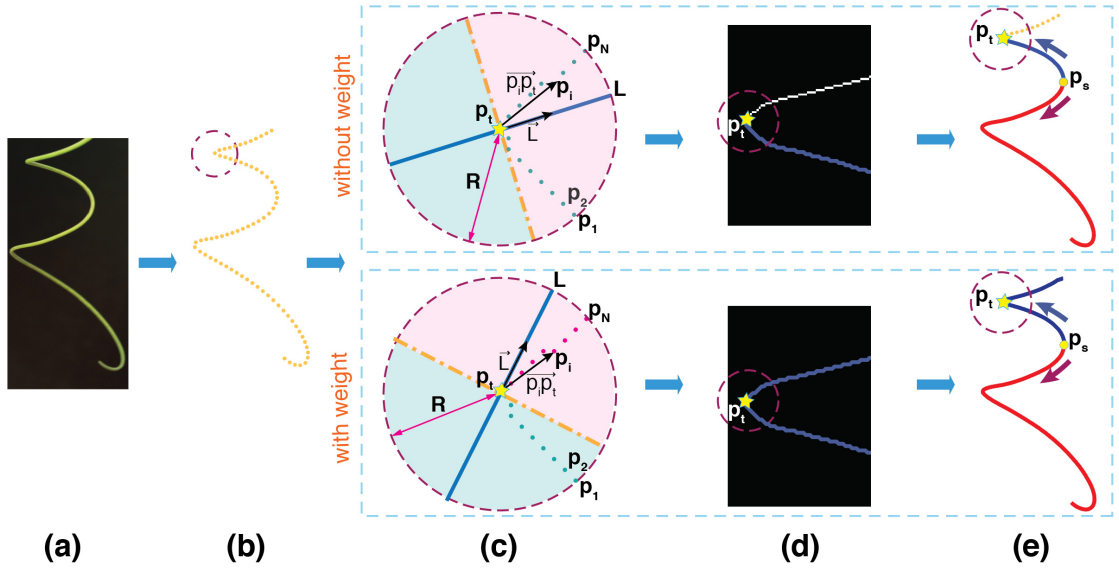
$$\mathcal{E}_{fit}(p_i, p_j) = \min_{a_{ij}, b_{ij}} \left(\sum_{t=i}^{j} \left| a_{ij} \cdot s_t + b_{ij} - \kappa_t \right|^2 \right)$$

arclength curvature

Proposed Method

Weighted Moving Least Squares Method – Step 2

(based on the previous work [Jie Fan et al. Robosoft 2020])



Original tendril Skeletonization The comparison of sorting results

Automatic Selection of Segment Number – Step 4

Dynamic Programming with an Up-sweep Approach

$$\mathcal{J}(p_i, p_j) = \min_{i<k<j} \{\mathcal{J}(p_i, p_k) + \mathcal{J}(p_k, p_j), \epsilon + \mathcal{E}_{fit}(p_i, p_j)\}$$

penalty to generate a single segment

slope intercept

$$\mathcal{E}_{fit}(p_i, p_j) = \min_{a_{ij}, b_{ij}} \left(\sum_{t=i}^{j} \left| a_{ij} \cdot s_t + b_{ij} - \kappa_t \right|^2 \right)$$

arclength curvature

2D Piece-wise Clothoid Representation - Step 5

2D Clothoid Spiral with Fresnel Integrals

$$\begin{pmatrix} x \\ y \end{pmatrix} = \pi B \begin{pmatrix} \mathcal{C}(l) \\ \mathcal{S}(l) \end{pmatrix}$$

scaling factor

$$\mathcal{S}(l) = \int_0^l \sin \frac{\pi}{2}\tau^2 \, d\tau \approx \frac{1}{2} - R(l) \cos\left(\frac{1}{2}\pi \left(A(l) - l^2\right)\right)$$

$$\mathcal{C}(l) = \int_0^l \cos \frac{\pi}{2}\tau^2 \, d\tau \approx \frac{1}{2} - R(l) \sin\left(\frac{1}{2}\pi \left(A(l) - l^2\right)\right)$$

$$A(l) = \frac{1}{0.803l^3 + 1.886l^2 + 2.524l2}$$

$$R(l) = \frac{0.506l + 1}{1.79l^2 + 2.054l + \sqrt{2}}$$

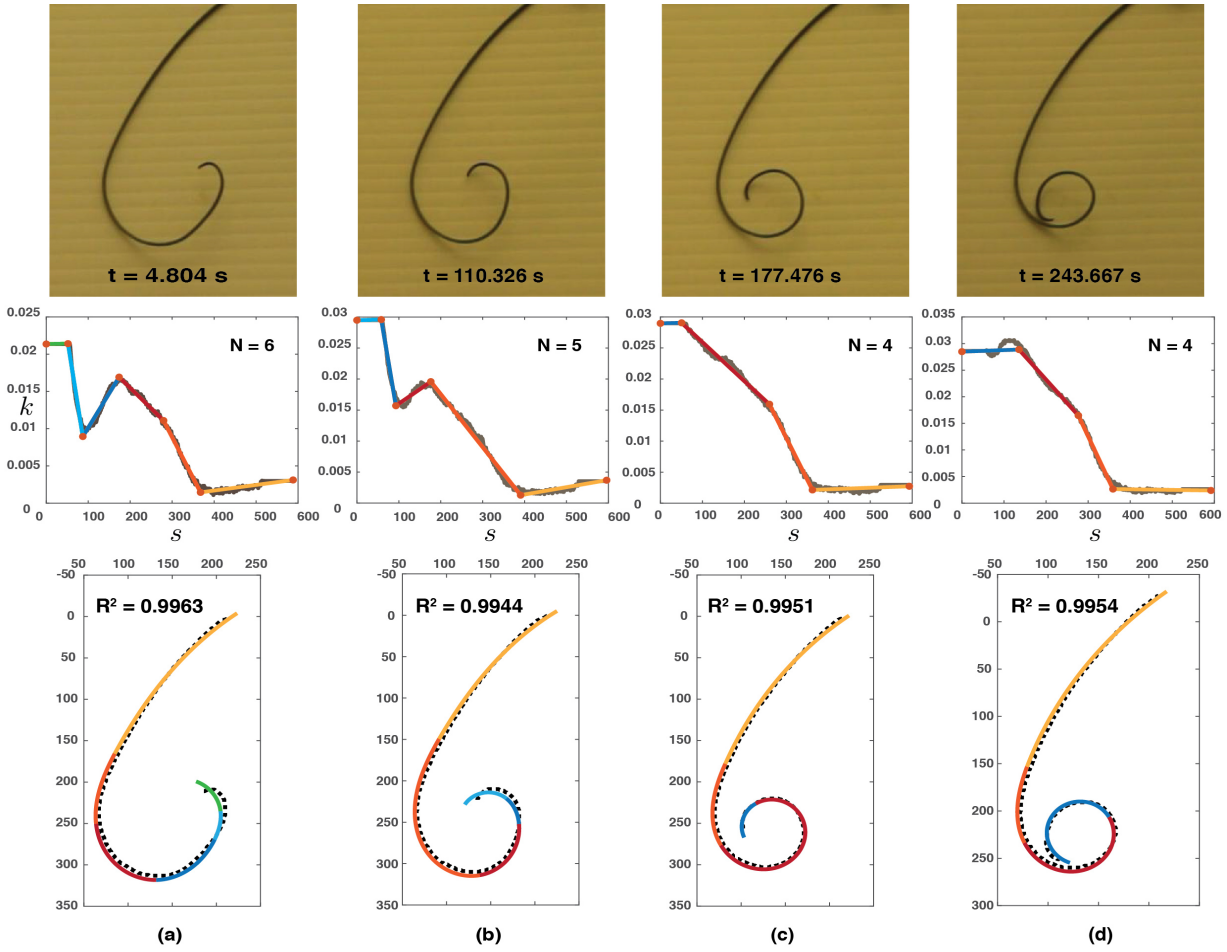
Approximation with 1.7 x 10-3 error on R(l) and A(l)

Results

An Image-based Method for the Morphological Analysis of Tendrils with 2D Piece-wise Clothoid Approximation Model

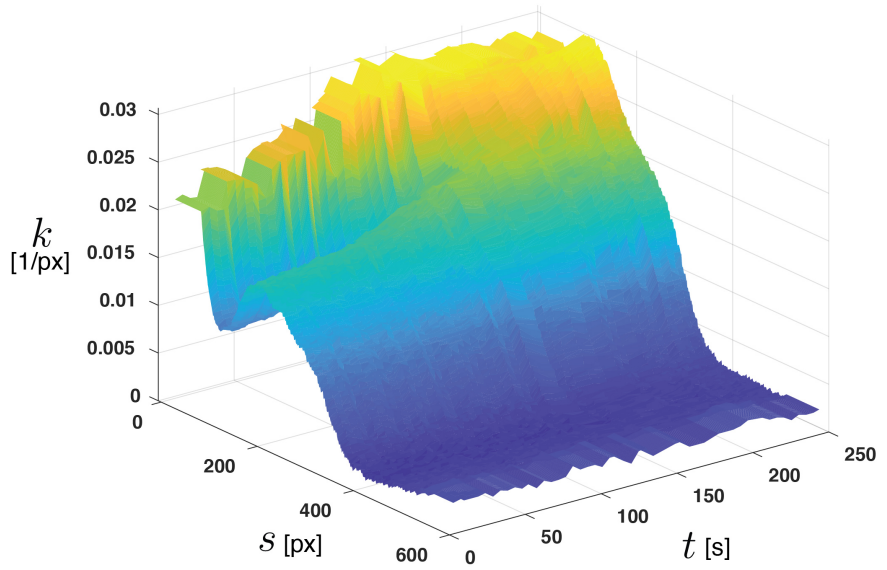
Jie Fan[1,2], Francesco Visentin[2], Emanuela Del Dottore[2], and Barbara Mazzolai[2]

[1]The BioRobotics Institute, Scuola Superiore Sant'Anna, Pontedera, Italy
[2]Center for Micro-BioRobotics@SSSA, Istituto Italiano di Tecnologia, Italy



We found that 4 to 6 segments were enough to represent curling shapes with high accuracy.

With this approach we can analyze the changes over time in the morphology of continuum adaptive structures.



Future Works

- Extend 3D model to better analyze the shape and behavior of tendrils
- Consider self-occlusion of tendrils during their growing evolution in 3D space
- Analyze the morphological evolution of natural tendrils during support grasping
- Use the extracted feature to guide the design of tendril-like soft robots
- Investigating and developing control strategies for continuum growing robots

Future Works

- Extend 3D model to better analyze the shape and behavior of tendrils
- Consider self-occlusion of tendrils during their growing evolution in 3D space
- Analyze the morphological evolution of natural tendrils during support grasping
- Use the extracted feature to guide the design of tendril-like soft robots
- Investigating and developing control strategies for continuum growing robots

Thanks!

For any question of this work, please contact with us at the following email addresses:

jie.fan@iit.it
francesco.visentin@iit.it
emanuela.deldottore@iit.it
barbara.mazzolai@iit.it

BSR Bioinspired Soft Robotics lab
https://bsr.iit.it/
https://growbot.eu/

LIVING MACHINES 2020

iit BSR ISTITUTO ITALIANO DI TECNOLOGIA BIOINSPIRED SOFT ROBOTICS

GROWBOT