An Analytical Loading Model for n-Tendon Continuum Robots

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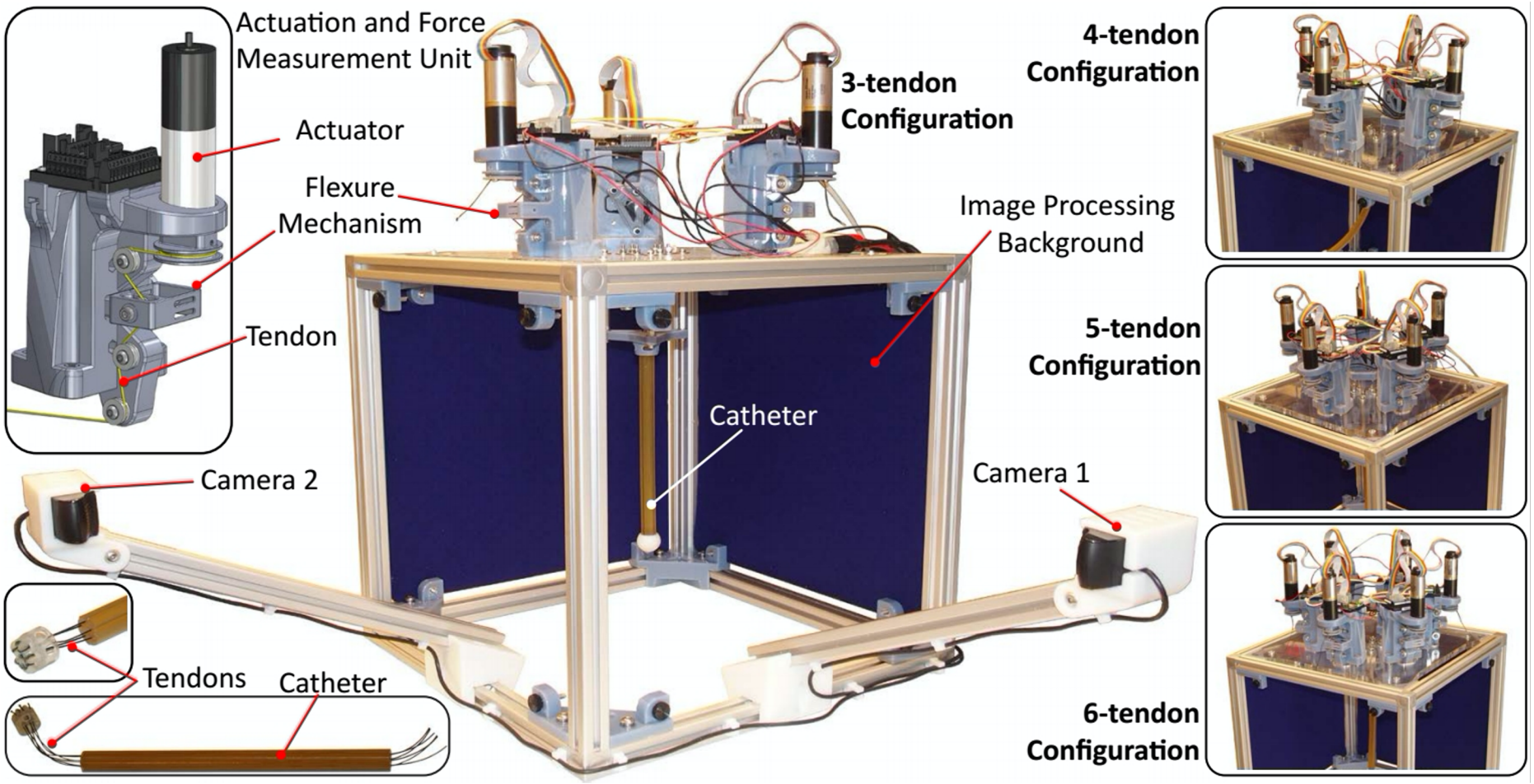
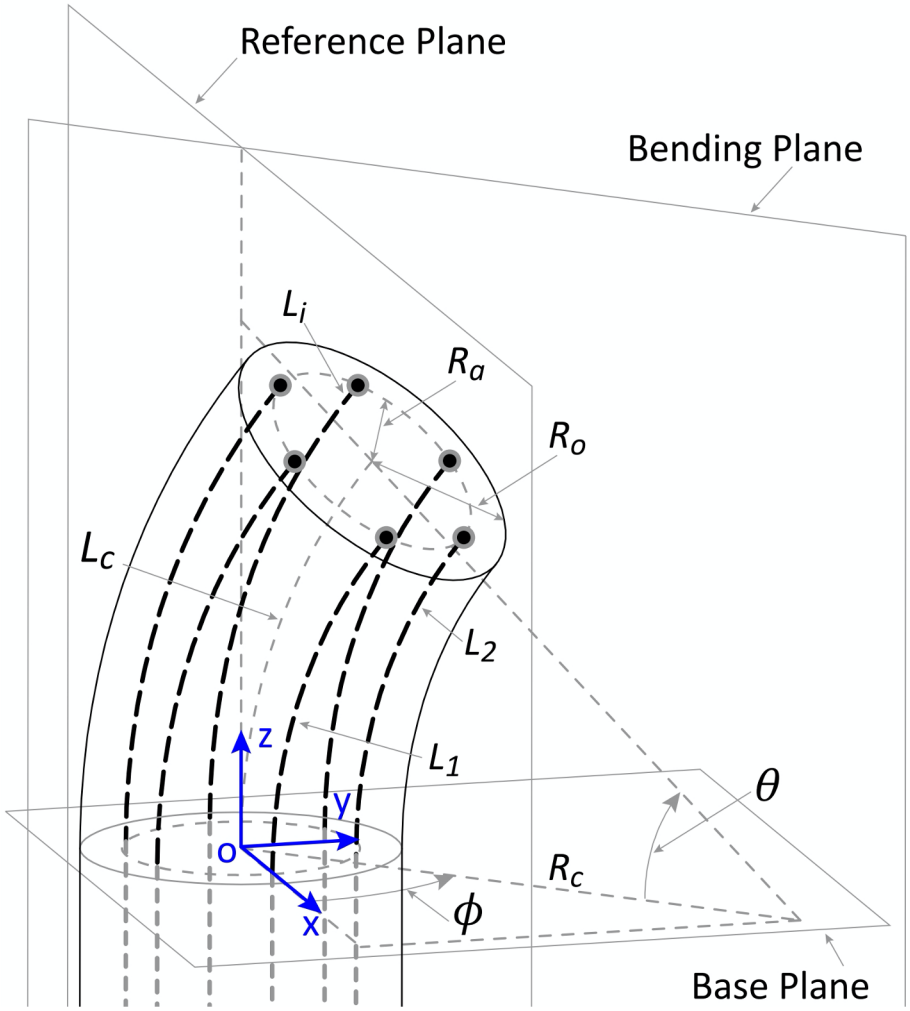
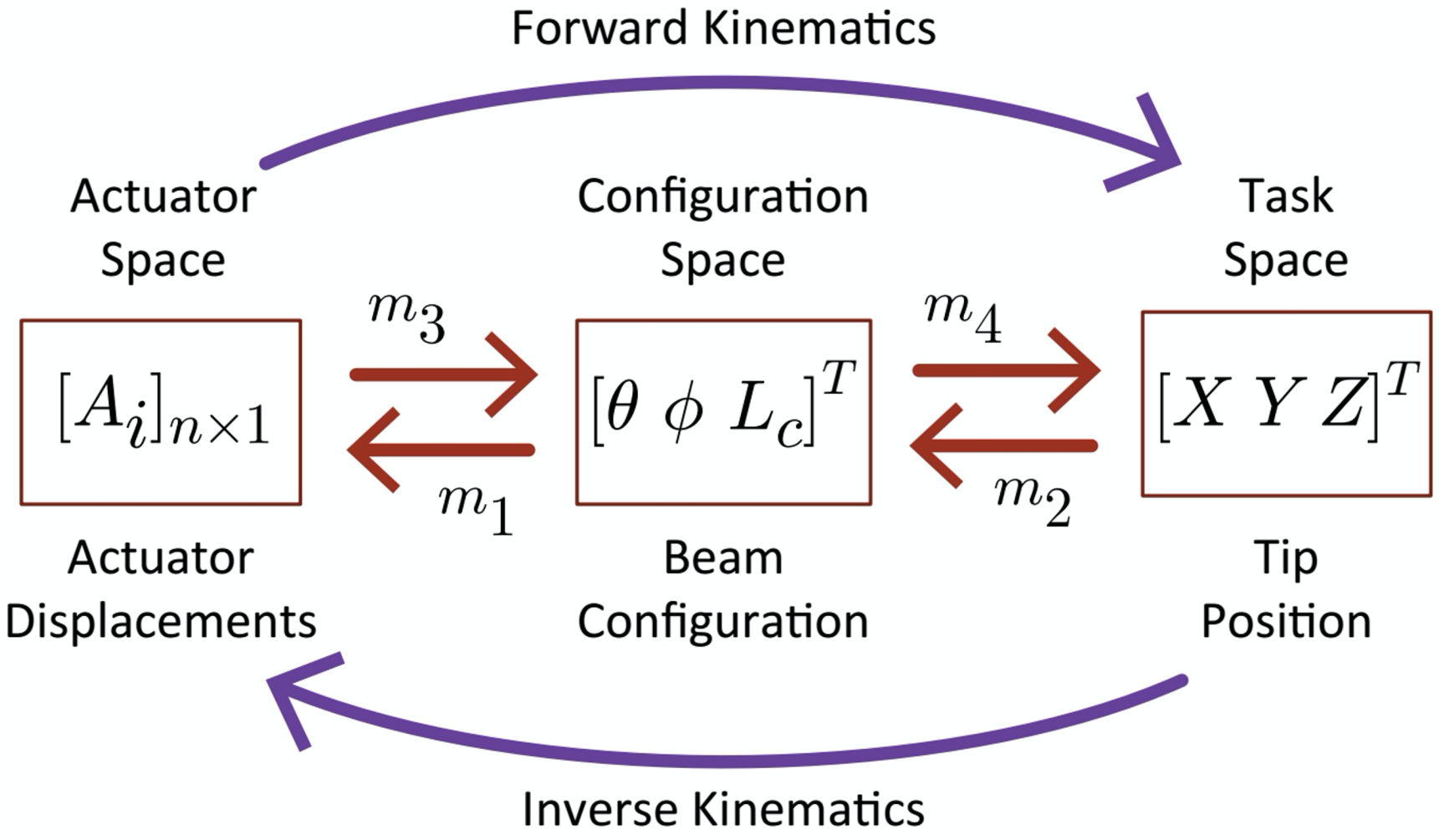
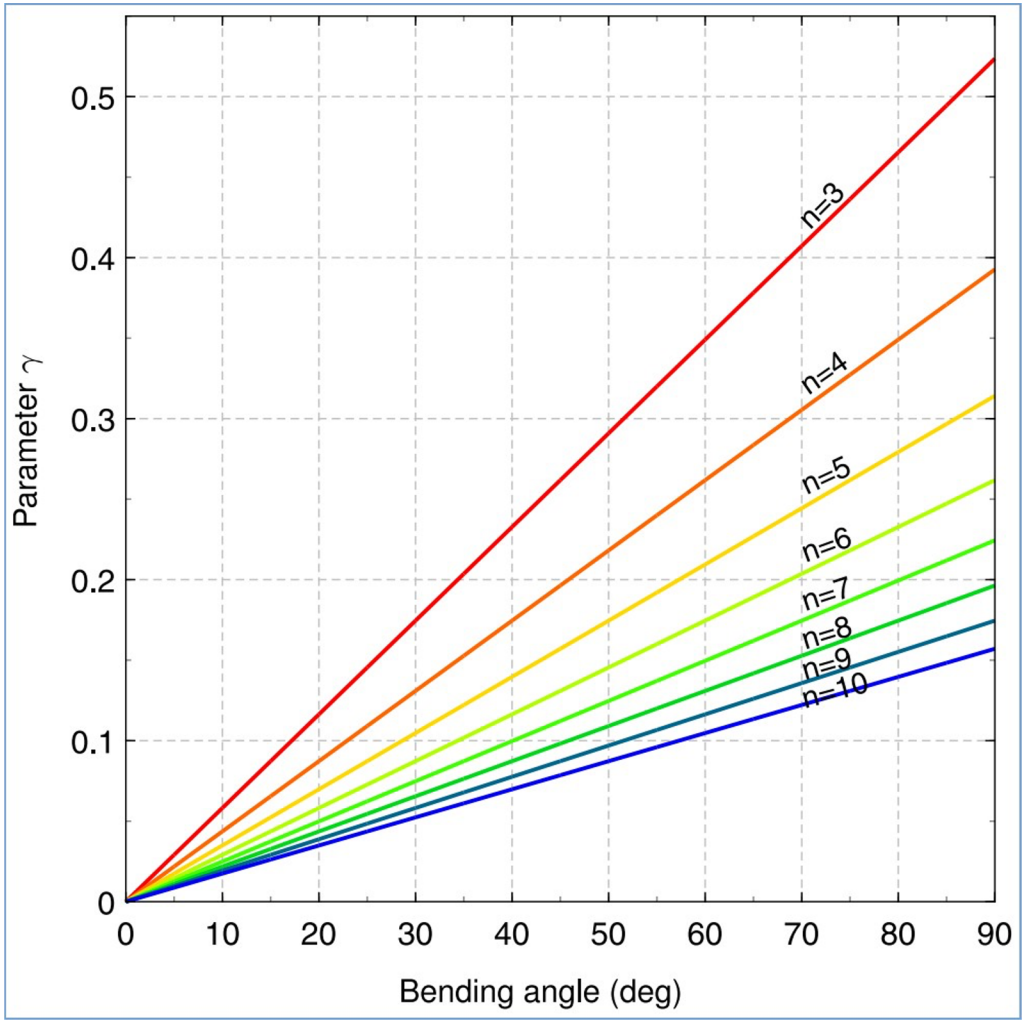
Description: One of the key design parameters in tendon-driven continuum robots is the number of tendons and the tendon loading distribution. A load model is also helpful for avoiding slack in tendons that causes control inefficiency and inaccuracy. A quasistatic model of n-tendon continuum robots is derived using the Euler–Lagrange formulation. The model is employed to derive an analytical loading model for equidistant tendon tensions for any given beam configuration within the workspace. The model accounts for the bending and axial compliance of the manipulator as well as tendon compliance. Features of the proposed model are discussed and some of the potential applications are explained. Based on the proposed model, a slack avoidance algorithm with analytical formulation is developed to dynamically optimize the tendon loads while preventing slack in tendons for a given configuration. The proposed model is experimentally validated in a multi-tendon continuum robot system for four case studies of three- to six-tendon arrangements in open-loop control architecture. A stereo vision-based three-dimensional reconstruction system measures the beam configuration and properties for each of the three- to six-tendon continuum robots. The effect of number of tendons on the tension loads in n-tendon continuum robots is studied. A quantitative dimensionless relationship between the number of tendons, the maximum tendon loads, and the bending angles is developed that may be used as a design tool for tradeoff among the complexity and required force and size.

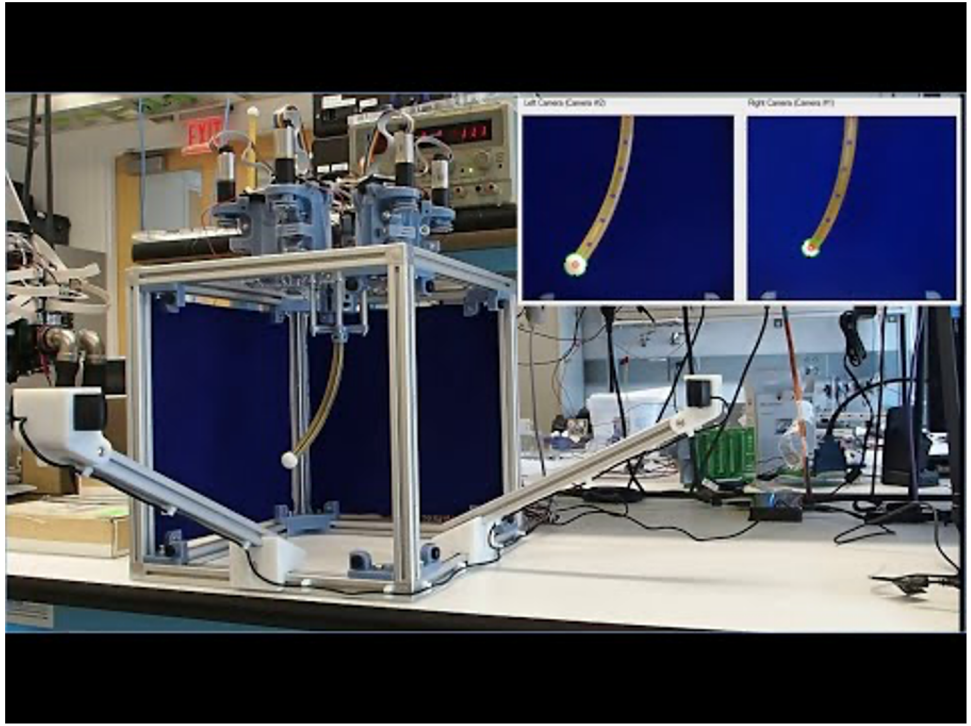
2013 – 2018


Actuation and Force Measurement Unit
Actuator
Flexure Mechanism
Tendon
3-tendon Configuration
Image Processing Background
Catheter
Camera 2
Camera 1
Tendons
Catheter
4-tendon Configuration
5-tendon Configuration
6-tendon Configuration


Reference Plane
Bending Plane
L_i
R_a
R_o
L_c
L_2
L_1
z
y
o
x
θ
R_c
ϕ
Base Plane


Forward Kinematics
Actuator Space
Configuration Space
Task Space
$[A_i]_{n\times 1}$
m_3
m_1
$[\theta\ \phi\ L_c]^T$
m_4
m_2
$[X\ Y\ Z]^T$
Actuator Displacements
Beam Configuration
Tip Position
Inverse Kinematics


Parameter γ
Bending angle (deg)
0
0.1
0.2
0.3
0.4
0.5
0
10
20
30
40
50
60
70
80
90
n=3
n=4
n=5
n=6
n=7
n=8
n=9
n=10


Left Camera (Camera #2)
Right Camera (Camera #1)