SoRoSim
Soft Robot Simulator

SoRoSim: a MATLAB®Toolbox for Soft Robotics Based on the Geometric Variable-strain Approach

Anup Teejo Mathew, Ikhlas Ben Hmida and Federico Renda
Khalifa University, Abu Dhabi UAE

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Introduction

Soft robots are robots that are made of a highly compliant material, typically having Elastic moduli ranging from 10^4 to 10^9 Pa. The compliant nature of these robots makes them similar in softness to human soft tissues. Recent medical soft robot designs have been explored for use in applications such as rehabilitation, surgical, and diagnostic procedures.

Clinical applications of soft robots in upper and lower body rehabilitation include assisting patients in regaining motor function, especially in post-stroke paralysis, through repeatedly moving joints while providing support in one or more degrees of freedom (DoFs) .

Soft robots have also been explored for use in medical procedures to reduce the risk of damaging tissue, increase flexibility, improve biocompatibility, enhance existing technology, and model biological functions. Advancements have also been made in soft robotics for surgical applications including colonoscopy, ventricular assistance and modeling, and urinary catheters [1].

Despite the growing interest in the field of soft robotics, there is still no unified platform to mathematically represent a soft robot as accurately as rigid robots and facilitate the simulation of different types of manipulators. There is however an abundance of separately functioning geometric and mechanical models such as the Piecewise Constant Curvature and the Continuous Cosserat models which allow the modeling of soft robotic systems with varying degrees of fidelity. The software available for modeling soft robotics currently relies mainly on these types of independent models. This toolbox however makes use of a unifying model, the Geometric Variable Strain model [2], that spans the modeling of both soft and rigid robots.

Method

The programming approach used in creating this toolbox was Object-Oriented Programming. This approach entails software design around data, or objects, rather than functions and logic. OOP comes with many advantages as it provides a well-structured map of the program and allows easy access and adjustment to object-specific data. OOP also allows reusability, once an object is defined and saved in MATLAB's workspace the user can perform multiple manipulations without having to redefine the object. This toolbox consists of 3 classes that work together to form a powerful simulation tool that employs the GVS model to analyze soft, rigid and hybrid open-chain manipulators.

The Geometric Variable Strain Approach:

Is a model based on a strain parametrization of the soft links represented by Cosserat rods. The strains ae calculated as follows:

$$\boldsymbol{\xi}_i(X_i) \ = \boldsymbol{B}_{\xi_i}\boldsymbol{q}_i + \boldsymbol{\xi}_i^*$$

Where $\boldsymbol{B}_{\xi_i}(X_i) \ \in \mathbb{R}^{6\times n_i}$ (n_i being the number of DoFs of link i) is a matrix function, whose columns form the basis for the strain field, $q_i \in \mathbb{R}^{n_i}$ is the vector of coordinates in that basis, and $\boldsymbol{\xi}_i^*(X_i) \in \mathbb{R}^6$ is a reference strain whose primary function is to model non-zero yet constrained strains such as inextensibility. $\boldsymbol{B}_{\xi_i}(X_i)$ is constant for rigid joints and in the case of piecewise constant strain [3].

The GVS model is geometrically-exact and generalizes the geometric theory of rigid robotics to hybrid systems of soft and rigid links with multi-dimensional joints and distributed actuation forces. The generalized equation of motion is expressed as:

$$M\ddot{q} + C\dot{q} + Kq = Bu + F$$

Where J_i is the geometric Jacobian of a link i, and:

$$B(q) = diag_{i=0}^{N}\left({}^{i}S_i^T \ or \int_0^{L_i} B_{\xi_i}^T B_{\mathcal{T}_i} dX_i\right) \qquad C(q,\dot{q}) = \sum_{i=1}^{N}\int_0^{L_i} J_i^T\left(ad_{\eta_i}^{*}\bar{\mathcal{M}}J_i + \bar{\mathcal{M}}\dot{J}_i\right)dX_i$$

$$M(q) = \sum_{i=1}^{N}\int_0^{L_i} J_i^T\bar{\mathcal{M}}J_i dX_i \qquad F(q,\dot{q}) = \sum_{i=1}^{N}\int_0^{L_i} J_i^T\bar{\mathcal{F}}_{e_i} dX_i \qquad K = diag_{i=0}^{N}\left(\int_0^{L_i} B_{\xi_i}^T \Sigma_i B_{\xi_i} dX_i\right)$$

Results

The toolbox created is a powerful tool that can run static and dynamic simulations as well as solve. Using the toolbox one can plot and model widely varying soft, rigid and hybrid links and open-chain manipulators. The toolbox can generate plots for a given a joint angle (q) vector or by solving the static and dynamic equations of motion. Some of the examples are shown below:

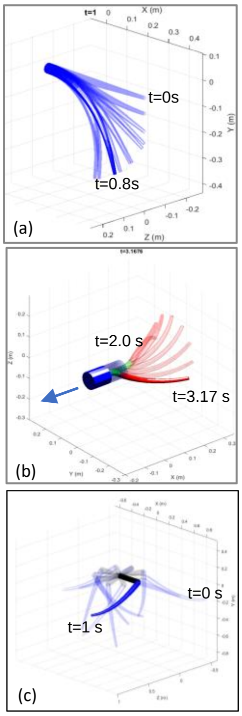
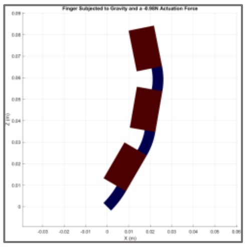


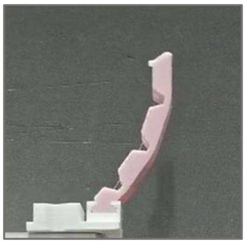
Figure 1 - (a) Superimposed plots of a cantilever soft beam subjected to gravitational force (b) Underwater locomotor propelled by the rotation of a soft filament (c) Hybrid system with an active revolute joint and a passive spherical joint attached to a soft body.

Discussion

The rigid robotics model of the toolbox was benchmarked by comparing plots obtained to those obtained by using other standard toolboxes such as the Peter Corke Robotics Toolbox. Due to the novelty of the soft robotics model used by the toolbox the soft and hybrid robotics simulations were validated against experiments and other verified models. The statics model was compared to simulations from (Renda et al., 2020), while the dynamics model was compared to (Boyer et al., 2020).

In order to test the toolbox's practical applications, a soft gripper prototype was designed and fabricated. The prototype is a 3 fingered gripper modeled after the Barrette hand gripper. Figure 2 (a) shows a gripper finger subjected to gravitational and actuation forces, while figure 2 (b) shows the simulated behavior of the finger using the toolbox.





References

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[2] **FF. Boyer, V. Lebastard, F. Candelier and F. Renda, "Dynamics of Continuum and Soft Robots: A Strain Parameterization Based Approach," in IEEE Transactions on Robotics, doi: 10.1109/TRO.2020.3036618. .**

[3] **F. Renda, F. Boyer, J. Dias and L. Seneviratne, "Discrete Cosserat Approach for Multisection Soft Manipulator Dynamics," in IEEE Transactions on Robotics, vol. 34, no. 6, pp. 1518-1533, Dec. 2018, doi: 10.1109/TRO.2018.2868815.**

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