OPEN PROJECT

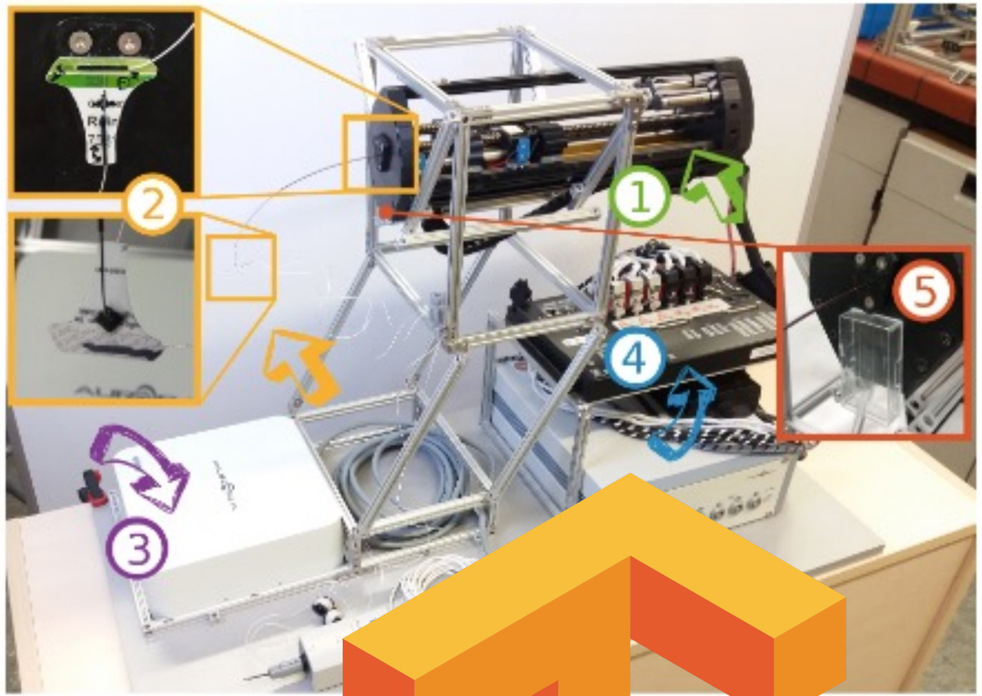
Reinhard Grassmann

UNIVERSITY OF TORONTO

Robotics Institute

continuum robotics lab

MY BACKGROUND AND EXPERIENCE



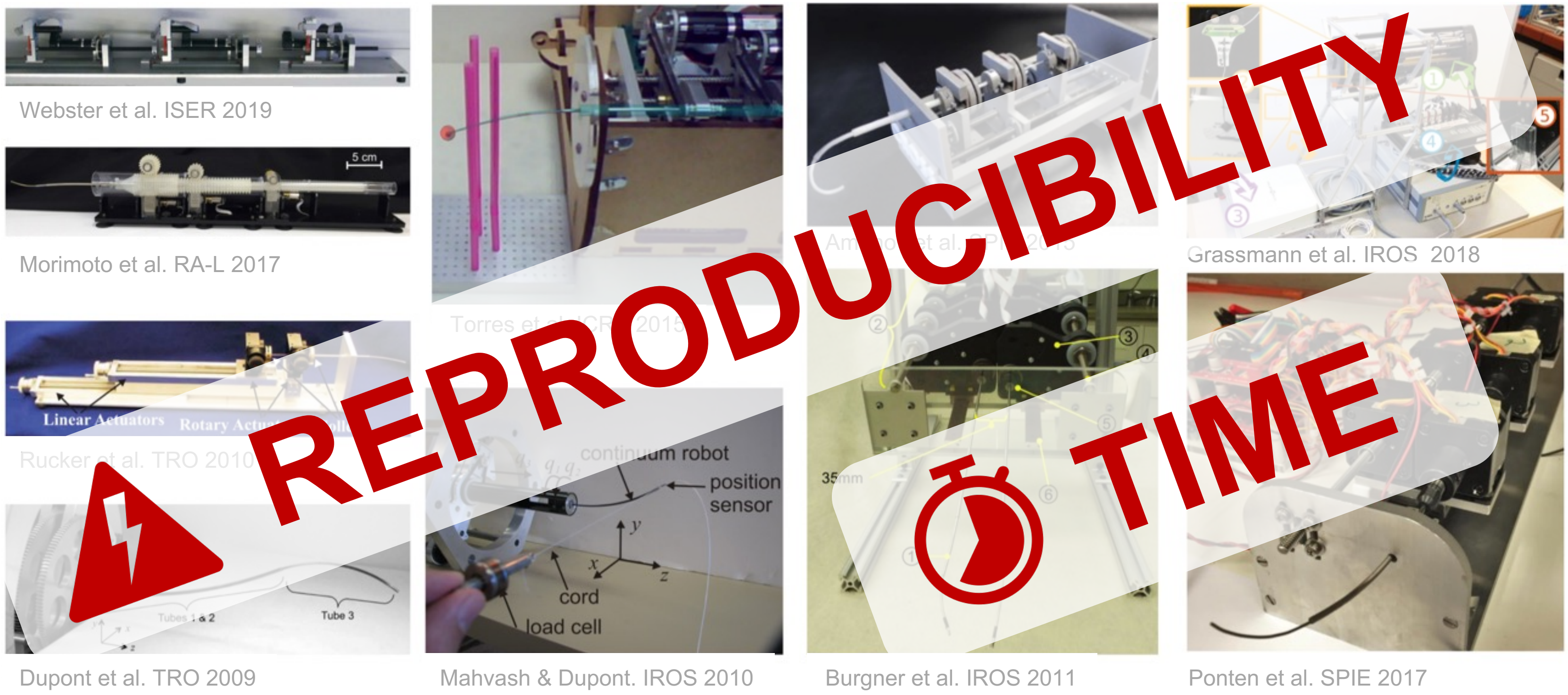
CONCENTRIC TUBE CONTINUUM ROBOTS

2006 to 2020

36 different CTCR prototypes

61.1% only used for single publication

Different prototypes per laboratory




OPEN PROJECT
Hardware
Software
Blog
http://www.opencontinuumrobotics.com

ACTUATION MODULE

- high-torque brushless DC motor
- high resolution optical encoder
- low-gear-ratio transmission

↓

proprioceptive sensing

torque control

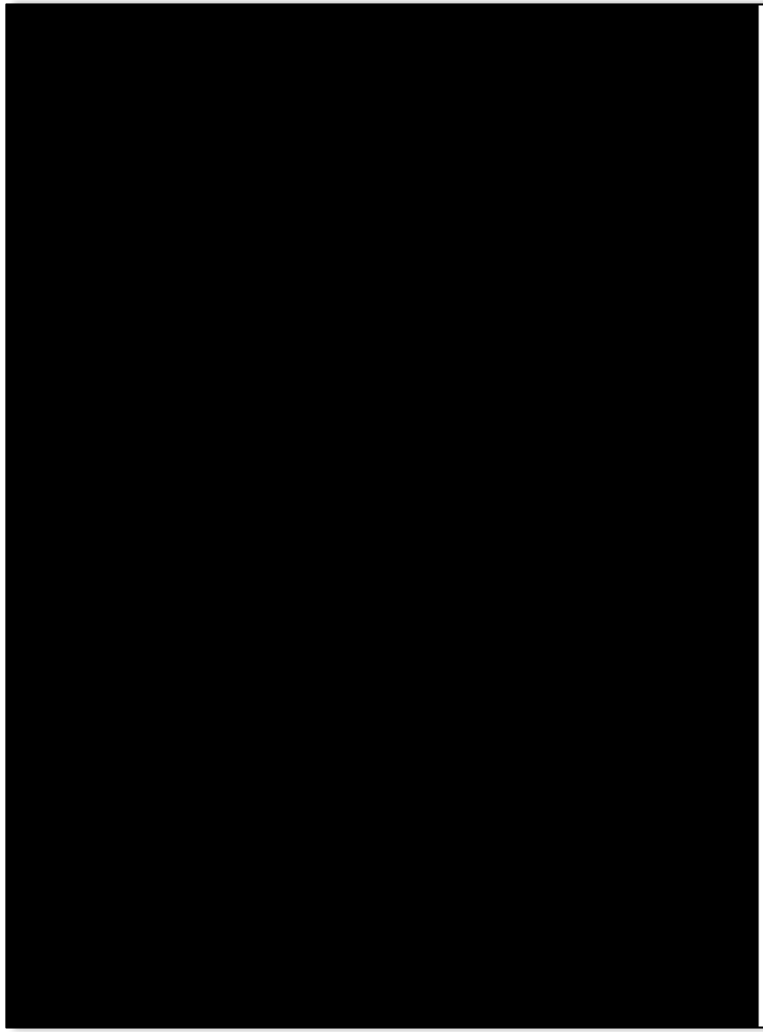
10 kHz low-level μ-controller
1 kHz high-level controller

modular
coupling to tubes/wires, tendons/rods

Grassmann, Shentu, Hamoda, Dewi, Burgner-Kahrs. Front. Robot. AI 2024
https://github.com/ContinuumRoboticsLab/OpenCR-Hardware

ONE ACTUATION MODULE



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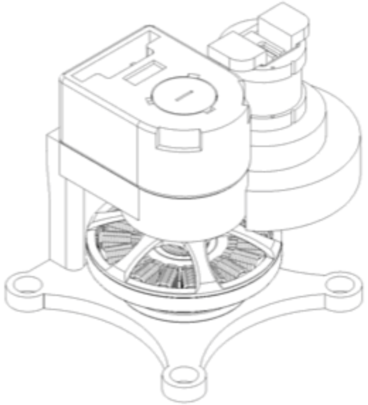
Modular Actuation Unit
Assembly Instructions

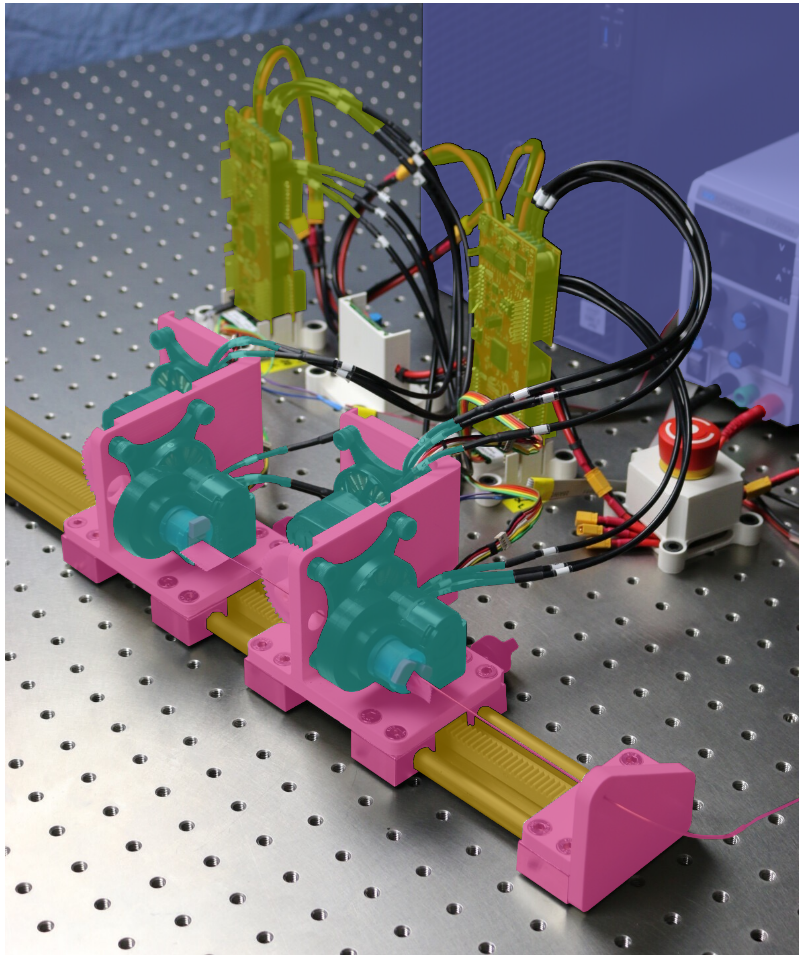


Grassmann, Shentu, Hamoda, Dewi, Burgner-Kahrs. Front. Robot. AI 2024

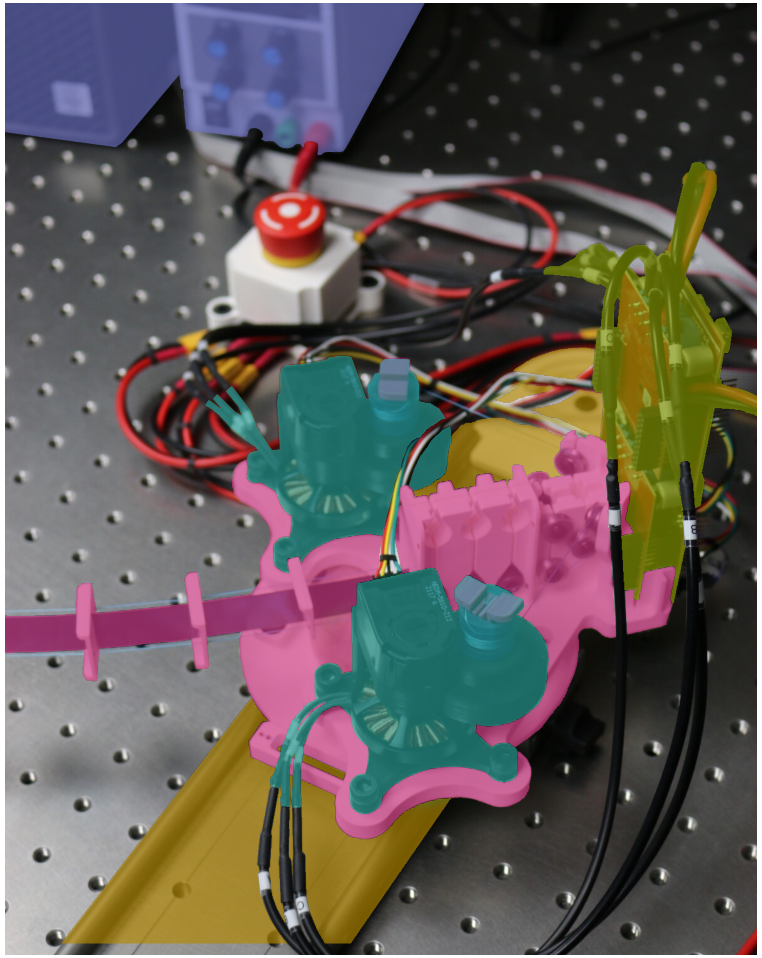
https://github.com/ContinuumRoboticsLab/OpenCR-Hardware

TO CREATE THEM ALL

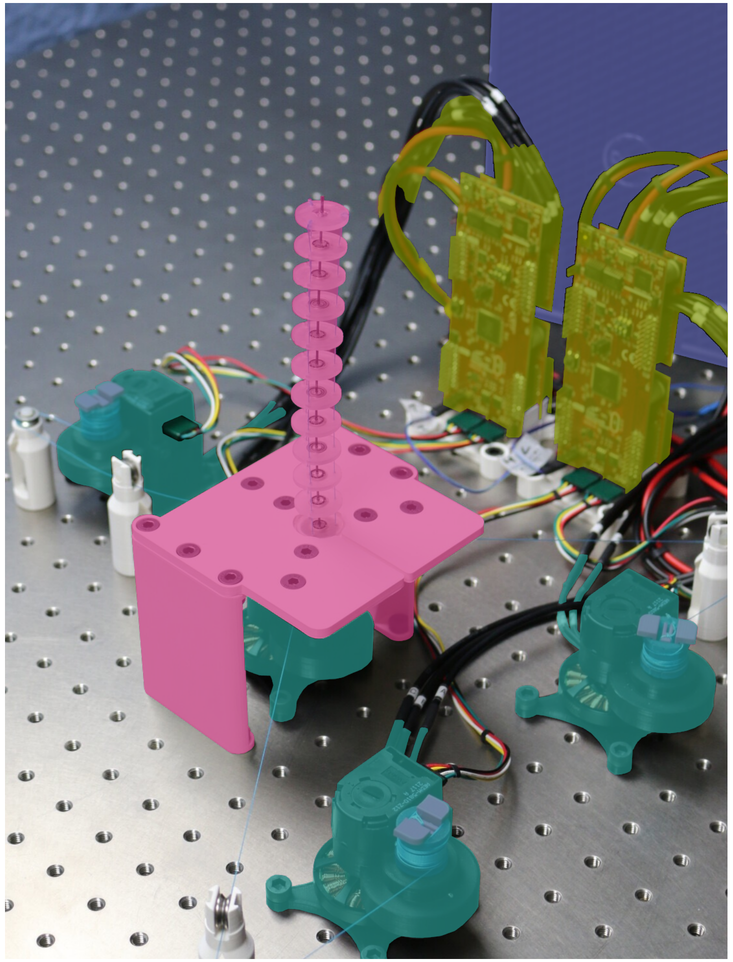
CONCENTRIC TUBE



PLANAR TENDON-DRIVEN



SPATIAL TENDON-DRIVEN



Grassmann, Shentu, Hamoda, Dewi, Burgner-Kahrs. Front. Robot. AI 2024

https://github.com/ContinuumRoboticsLab/OpenCR-Hardware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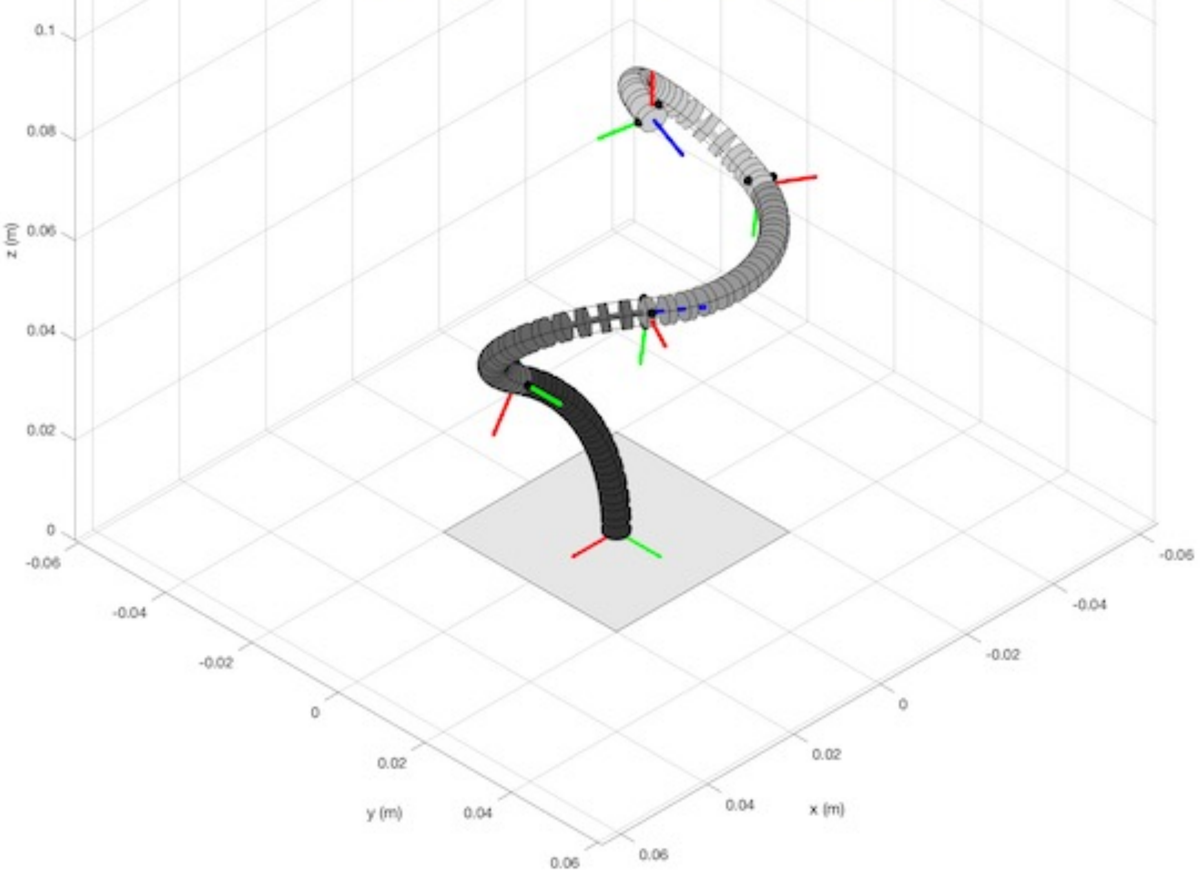
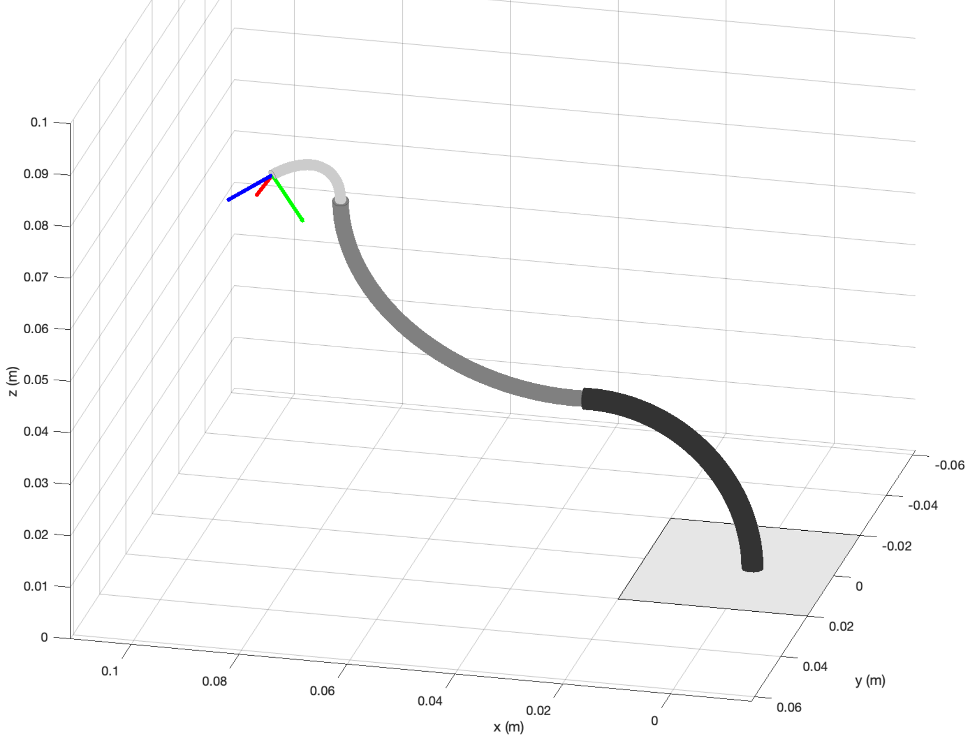
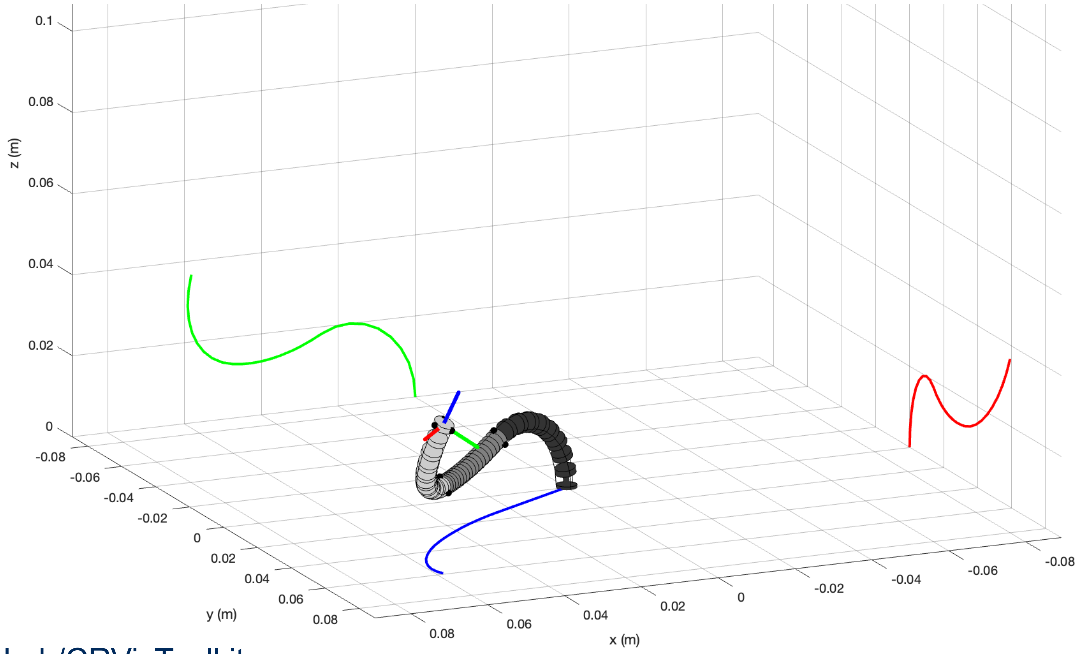
CR Vis Toolkit







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https://github.com/ContinuumRoboticsLab/CRVisToolkit

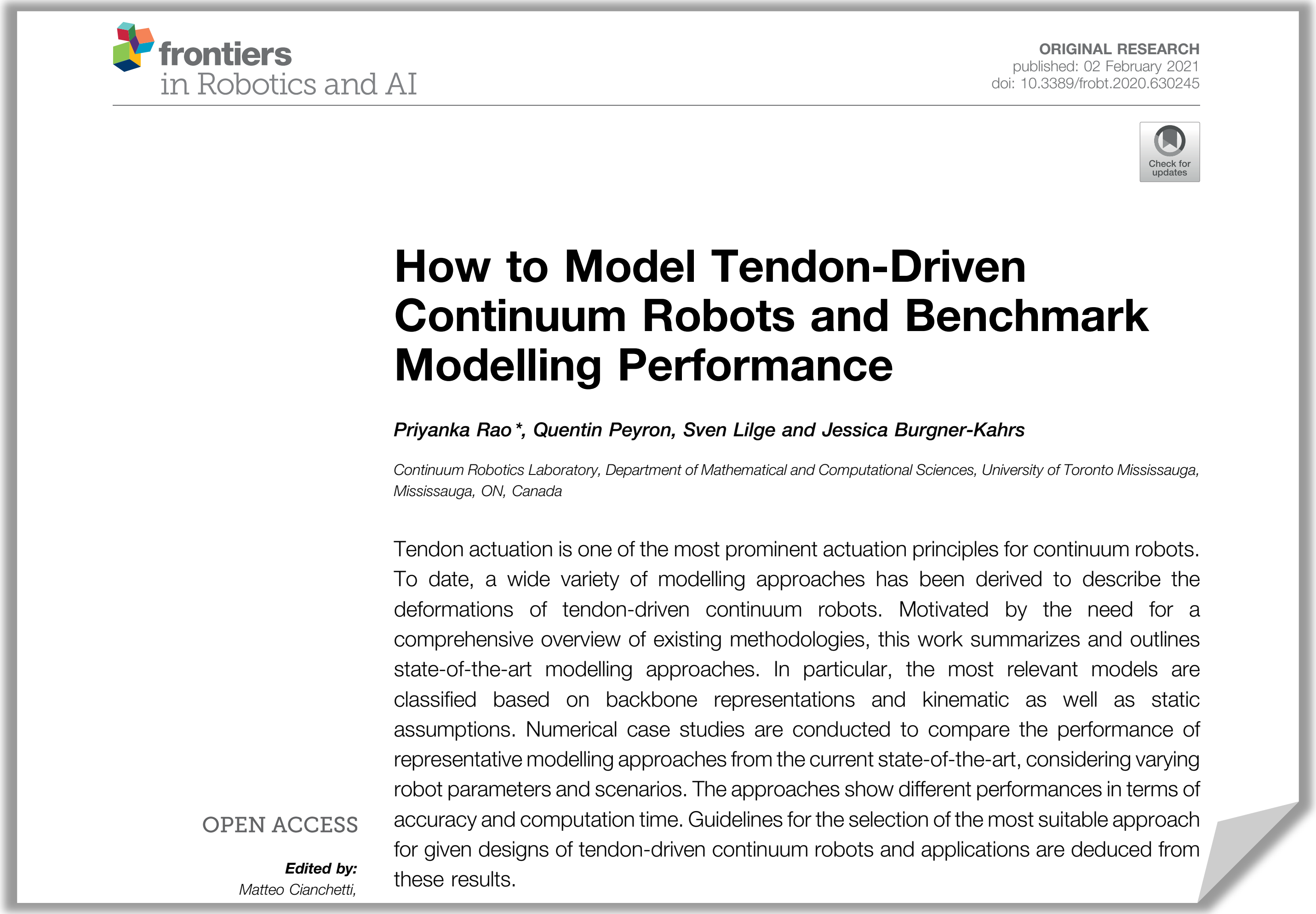
PHYSICS-BASED MODELING
PERFORMANCE BENCHMARK



Guidelines

Comparison
modeling performance

C++ and Matlab
implementations


frontiers
in Robotics and AI

ORIGINAL RESEARCH
published: 02 February 2021
doi: 10.3389/frobt.2020.630245

Check for updates

How to Model Tendon-Driven Continuum Robots and Benchmark Modelling Performance

Priyanka Rao, Quentin Peyron, Sven Lilge and Jessica Burgner-Kahrs*

Continuum Robotics Laboratory, Department of Mathematical and Computational Sciences, University of Toronto Mississauga, Mississauga, ON, Canada

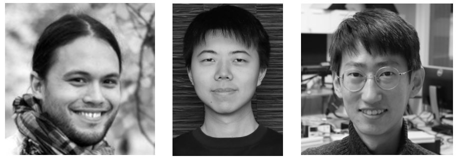
Tendon actuation is one of the most prominent actuation principles for continuum robots. To date, a wide variety of modelling approaches has been derived to describe the deformations of tendon-driven continuum robots. Motivated by the need for a comprehensive overview of existing methodologies, this work summarizes and outlines state-of-the-art modelling approaches. In particular, the most relevant models are classified based on backbone representations and kinematic as well as static assumptions. Numerical case studies are conducted to compare the performance of representative modelling approaches from the current state-of-the-art, considering varying robot parameters and scenarios. The approaches show different performances in terms of accuracy and computation time. Guidelines for the selection of the most suitable approach for given designs of tendon-driven continuum robots and applications are deduced from these results.

OPEN ACCESS

Edited by:
Matteo Cianchetti,

Rao, Peyron, Lilge, Burgner-Kahrs. Frontiers AI & Robotics 2021.
https://github.com/ContinuumRoboticsLab/tdcr-modeling

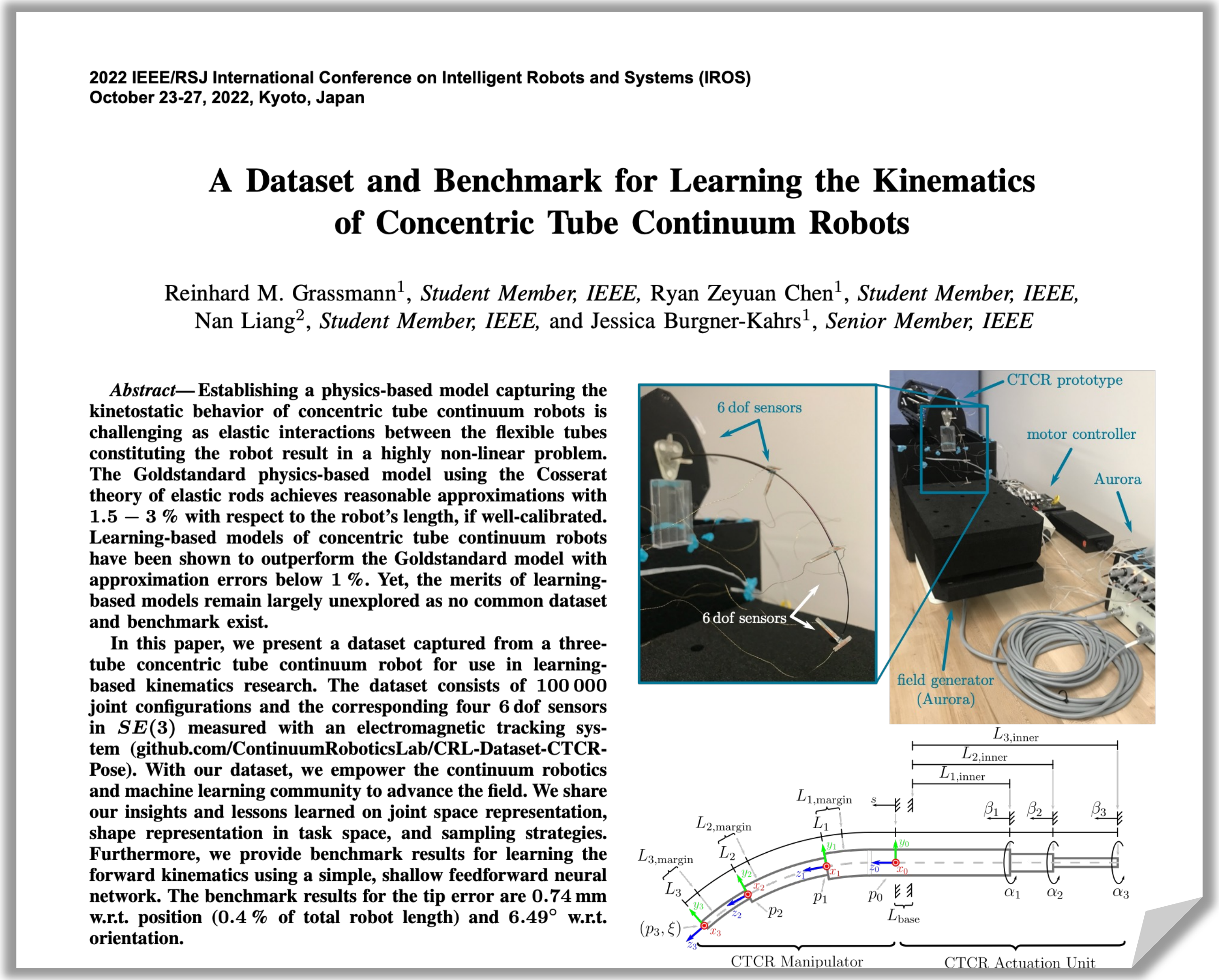
LEARNING-BASED MODELING
FIRST DATASET AND BENCHMARK



100k
joint space and task space

Effective representations
Sampling guidelines

Benchmark
FK: 0.4% w.r.t. length



2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)
October 23-27, 2022, Kyoto, Japan

A Dataset and Benchmark for Learning the Kinematics of Concentric Tube Continuum Robots

Reinhard M. Grassmann[1], *Student Member, IEEE,* Ryan Zeyuan Chen[1], *Student Member, IEEE,* Nan Liang[2], *Student Member, IEEE,* and Jessica Burgner-Kahrs[1], *Senior Member, IEEE*

***Abstract*— Establishing a physics-based model capturing the kinetostatic behavior of concentric tube continuum robots is challenging as elastic interactions between the flexible tubes constituting the robot result in a highly non-linear problem. The Goldstandard physics-based model using the Cosserat theory of elastic rods achieves reasonable approximations with $1.5 - 3$ % with respect to the robot's length, if well-calibrated. Learning-based models of concentric tube continuum robots have been shown to outperform the Goldstandard model with approximation errors below 1 %. Yet, the merits of learning-based models remain largely unexplored as no common dataset and benchmark exist.**

In this paper, we present a dataset captured from a three-tube concentric tube continuum robot for use in learning-based kinematics research. The dataset consists of 100 000 joint configurations and the corresponding four 6 dof sensors in $SE(3)$ measured with an electromagnetic tracking system (github.com/ContinuumRoboticsLab/CRL-Dataset-CTCR-Pose). With our dataset, we empower the continuum robotics and machine learning community to advance the field. We share our insights and lessons learned on joint space representation, shape representation in task space, and sampling strategies. Furthermore, we provide benchmark results for learning the forward kinematics using a simple, shallow feedforward neural network. The benchmark results for the tip error are 0.74 mm w.r.t. position (0.4 % of total robot length) and 6.49° w.r.t. orientation.

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Grassmann, Chen, Liang, Burgner-Kahrs. IEEE IROS 2022.
https://github.com/ContinuumRoboticsLab/CRL-Dataset-CTCR-Pose

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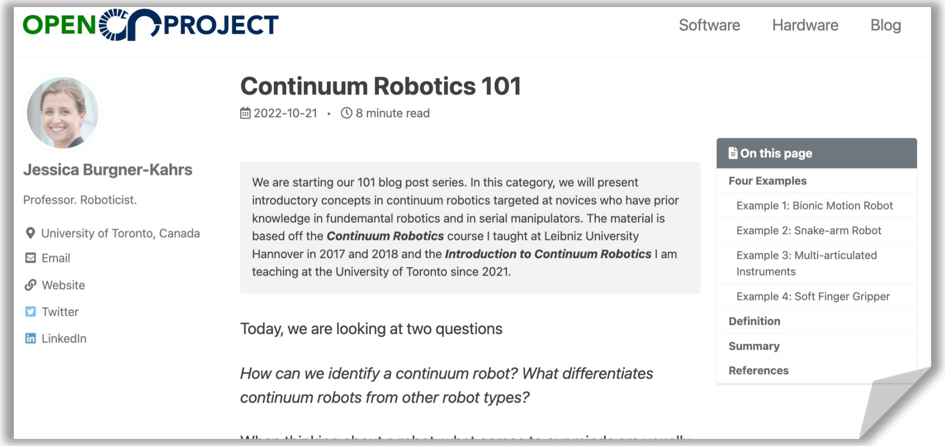

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Continuum Robotics 101

2022-10-21 · 8 minute read

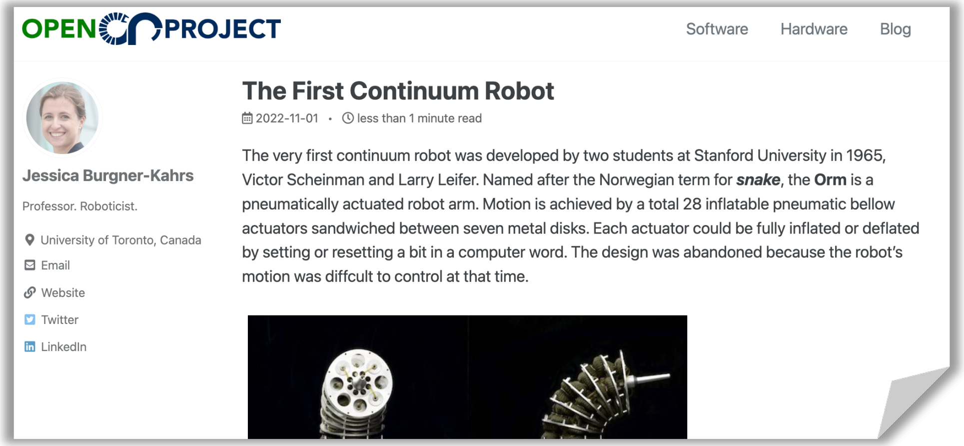
Jessica Burgner-Kahrs
Professor. Roboticist.
University of Toronto, Canada
Email
Website
Twitter
LinkedIn

We are starting our 101 blog post series. In this category, we will present introductory concepts in continuum robotics targeted at novices who have prior knowledge in fundemental robotics and in serial manipulators. The material is based off the ***Continuum Robotics*** course I taught at Leibniz University Hannover in 2017 and 2018 and the ***Introduction to Continuum Robotics*** I am teaching at the University of Toronto since 2021.

Today, we are looking at two questions

How can we identify a continuum robot? What differentiates continuum robots from other robot types?

On this page
Four Examples
Example 1: Bionic Motion Robot
Example 2: Snake-arm Robot
Example 3: Multi-articulated Instruments
Example 4: Soft Finger Gripper
Definition
Summary
References



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The First Continuum Robot

2022-11-01 · less than 1 minute read

Jessica Burgner-Kahrs
Professor. Roboticist.
University of Toronto, Canada
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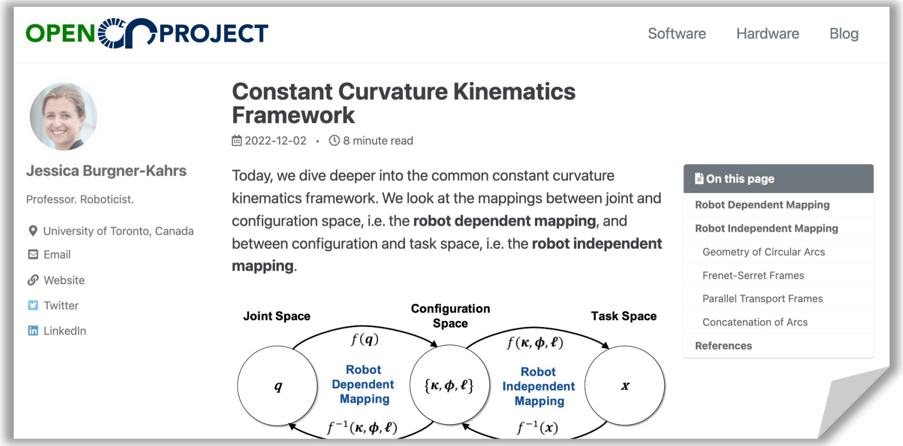
Website
Twitter
LinkedIn

The very first continuum robot was developed by two students at Stanford University in 1965, Victor Scheinman and Larry Leifer. Named after the Norwegian term for ***snake***, the **Orm** is a pneumatically actuated robot arm. Motion is achieved by a total 28 inflatable pneumatic bellow actuators sandwiched between seven metal disks. Each actuator could be fully inflated or deflated by setting or resetting a bit in a computer word. The design was abandoned because the robot's motion was diffcult to control at that time.



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Constant Curvature Kinematics Framework

2022-12-02 · 8 minute read

Jessica Burgner-Kahrs
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Today, we dive deeper into the common constant curvature kinematics framework. We look at the mappings between joint and configuration space, i.e. the **robot dependent mapping**, and between configuration and task space, i.e. the **robot independent mapping**.

On this page
Robot Dependent Mapping
Robot Independent Mapping
Geometry of Circular Arcs
Frenet-Serret Frames
Parallel Transport Frames
Concatenation of Arcs
References

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Algorithmic Motion Planning Meets Minimally-Invasive Robotic Surgery - Part 2

2024-01-14 · 7 minute read

Oren Salzman
Assistant Professor.
Technion, Israel
Email
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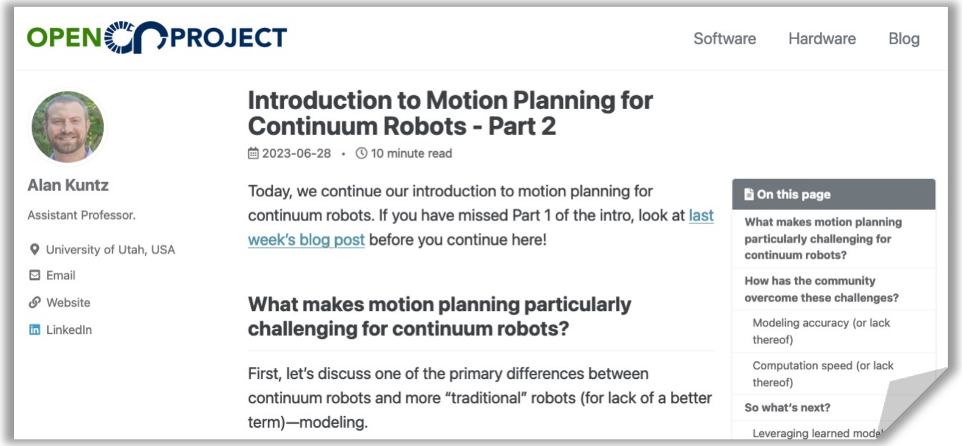
A Case Study of Inspection Using the CRISP Robot

In certain medical applications, physicians may want to inspect some region of interest for diagnostic purposes completing the procedure as fast as is safely possible to reduce costs and improve patient outcomes, especially if the patient is under anesthesia during the procedure. For example, the needle-diameter Continuum Reconfigurable Incisionless Surgical Parallel (CRISP) robot [1 2] was suggested to assist in the diagnosis of the cause of a

On this page
A Case Study of Inspection Using the CRISP Robot
Inspection Planning
What makes it challenging
IRIS - Incremental Random Inspection-roadmap Search
References



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Introduction to Motion Planning for Continuum Robots - Part 2

2023-06-28 · 10 minute read

Alan Kuntz
Assistant Professor.
University of Utah, USA
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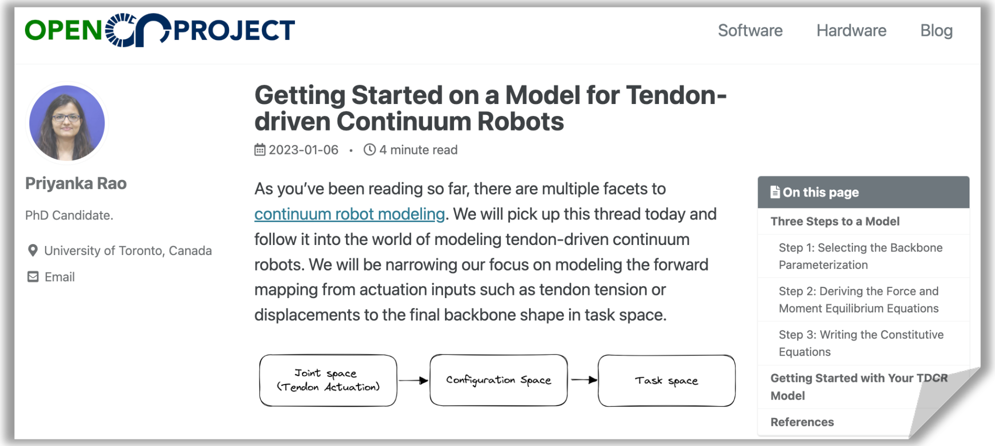
Website
LinkedIn

Today, we continue our introduction to motion planning for continuum robots. If you have missed Part 1 of the intro, look at last week's blog post before you continue here!

What makes motion planning particularly challenging for continuum robots?

First, let's discuss one of the primary differences between continuum robots and more "traditional" robots (for lack of a better term)—modeling.

On this page
What makes motion planning particularly challenging for continuum robots?
How has the community overcome these challenges?
Modeling accuracy (or lack thereof)
Computation speed (or lack thereof)
So what's next?
Leveraging learned mode



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Getting Started on a Model for Tendon-driven Continuum Robots

2023-01-06 · 4 minute read

Priyanka Rao
PhD Candidate.
University of Toronto, Canada
Email

As you've been reading so far, there are multiple facets to continuum robot modeling. We will pick up this thread today and follow it into the world of modeling tendon-driven continuum robots. We will be narrowing our focus on modeling the forward mapping from actuation inputs such as tendon tension or displacements to the final backbone shape in task space.

On this page
Three Steps to a Model
Step 1: Selecting the Backbone Parameterization
Step 2: Deriving the Force and Moment Equilibrium Equations
Step 3: Writing the Constitutive Equations
Getting Started with Your TDCR Model
References

101

history

research

hands-on

opinion

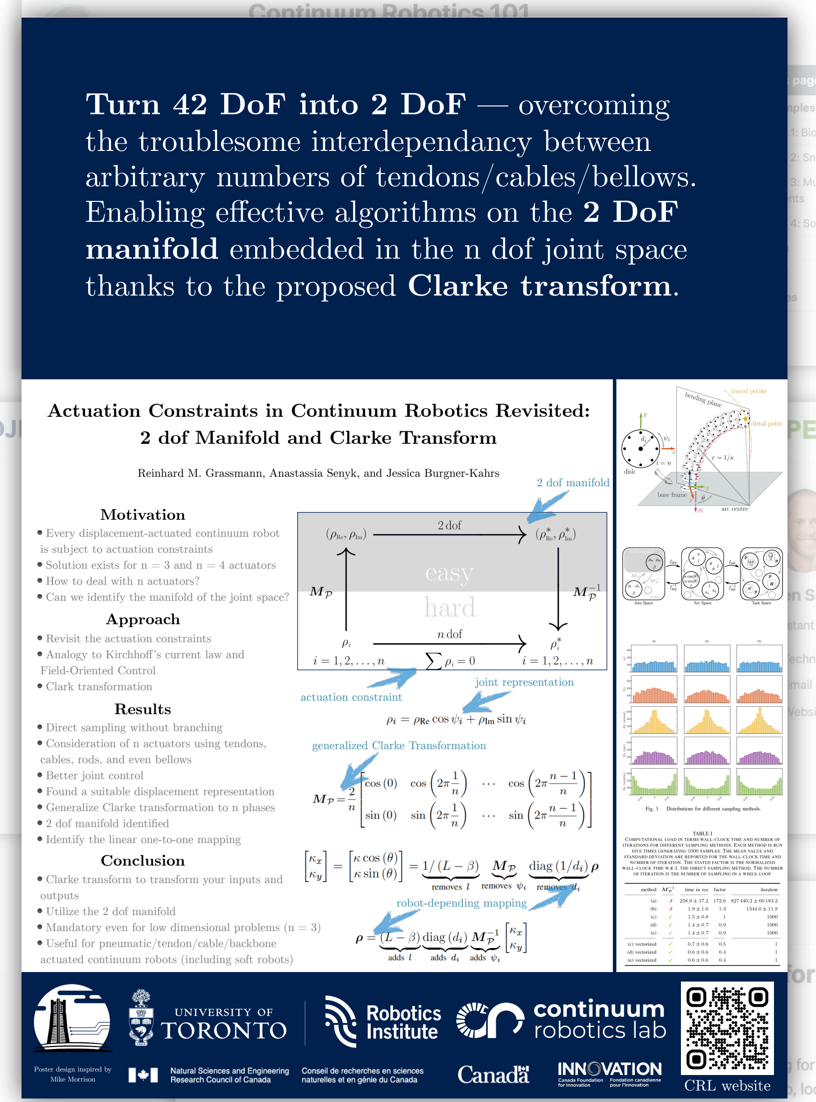
101

history

research

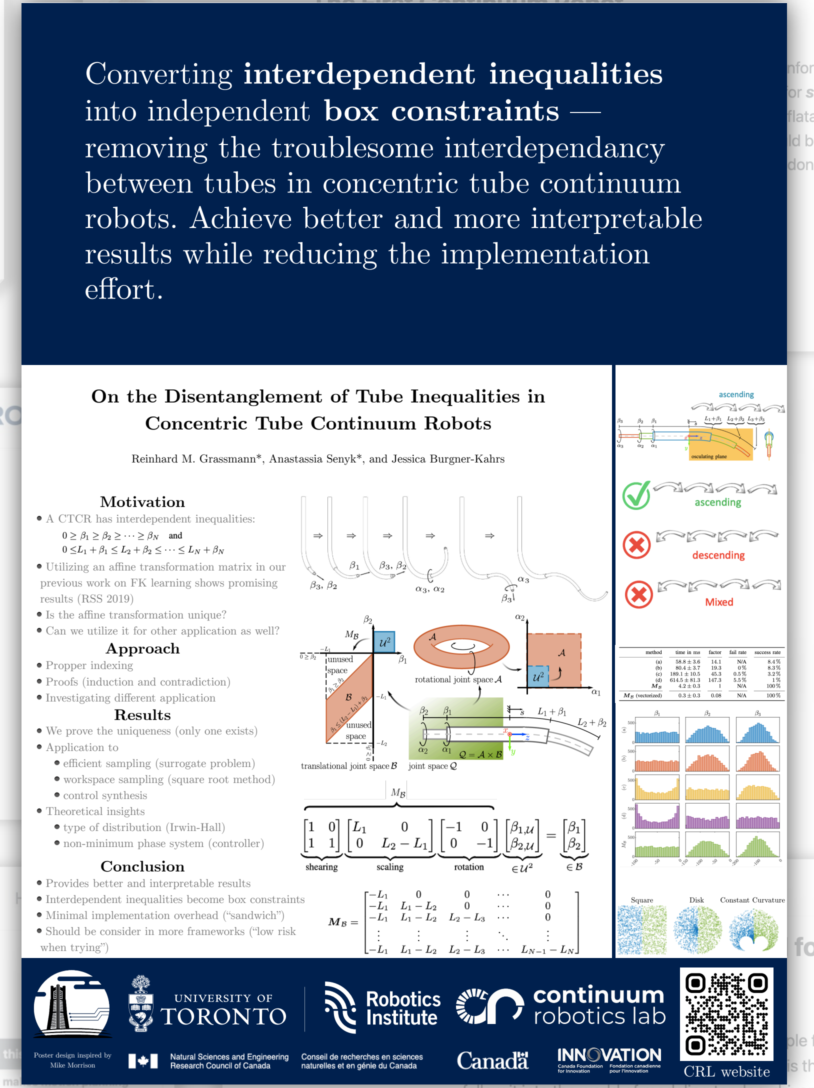
hands-on

opinion



Tuesday, Late Breaking Results

TuCL-EX.11



Wednesday, Paper Presentation

WeAT19-NT.1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Natural Sciences and Engineering Research Council of Canada

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