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ICRA 2021 WORKSHOP:
PARALLEL ROBOTS OR NOT PARALLEL ROBOTS? NEW FRONTIERS OF PARALLEL ROBOTICS

A Study on Flexible Parallel Robots via Additive Manufacturing

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1. Introduction

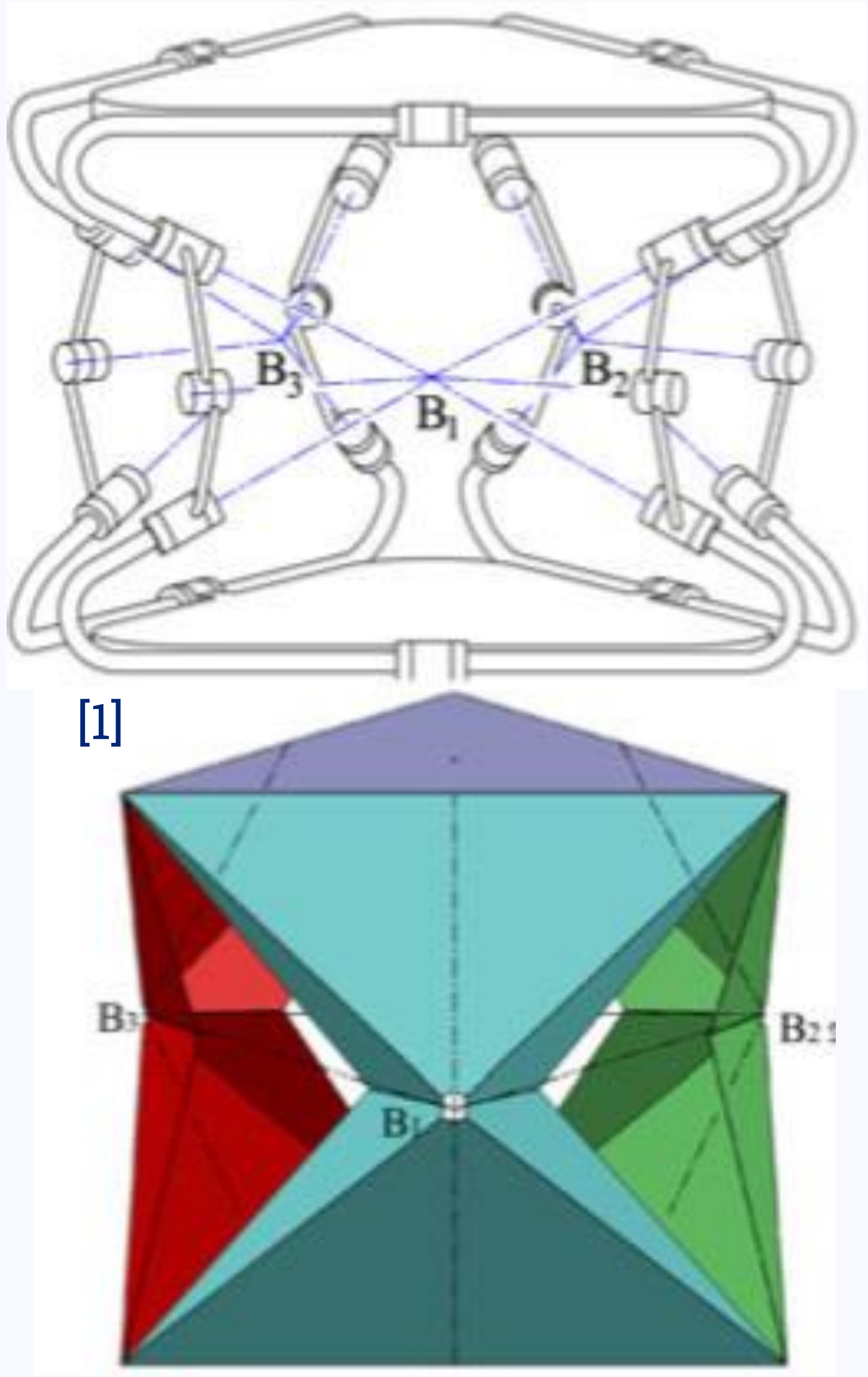
Motivation & State-of-the-Art

Rigid Parallel Robots

- Multiple closed loop kinematic chains – mechanical complexity

- Manufacturing and assembly can be challenging
- Trade-off between high friction and backlash
- Requires tight tolerances
- Difficult to achieve with Additive Manufacturing

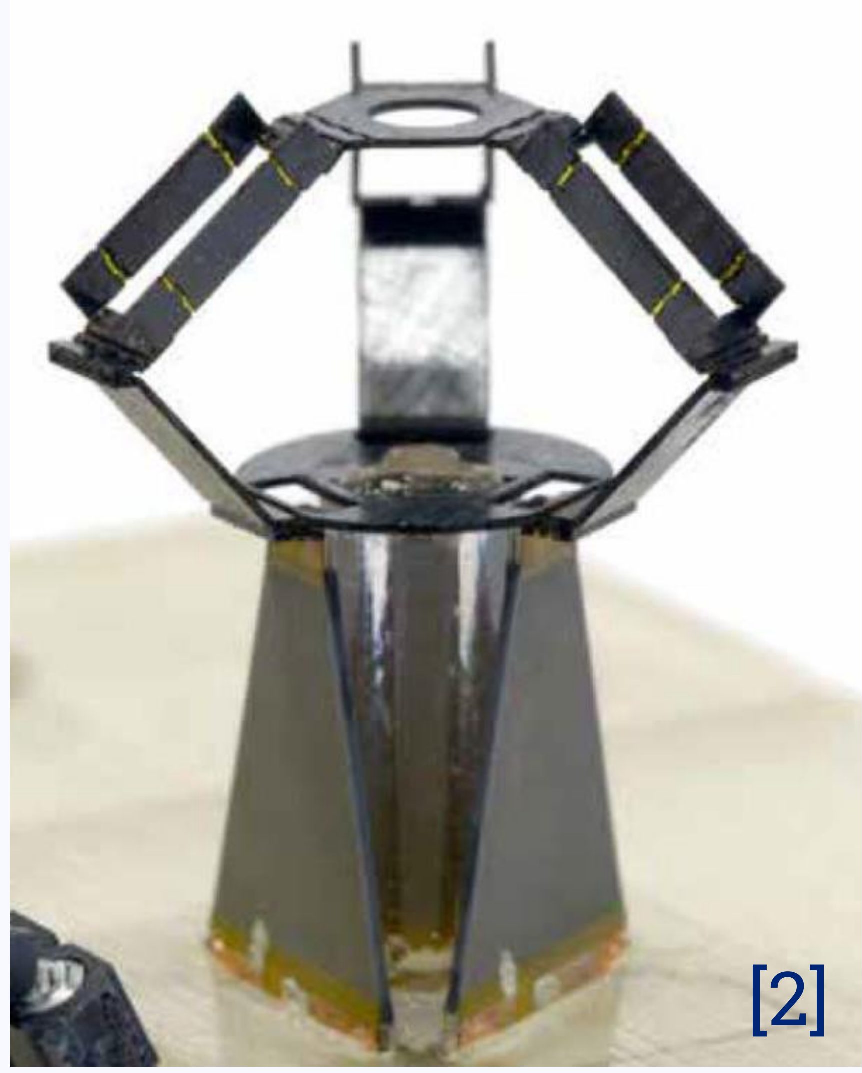
- One solution → ***Flexible Parallel Robots!***



[1] Salerno *et. al.*; IEEE T-RO 2016

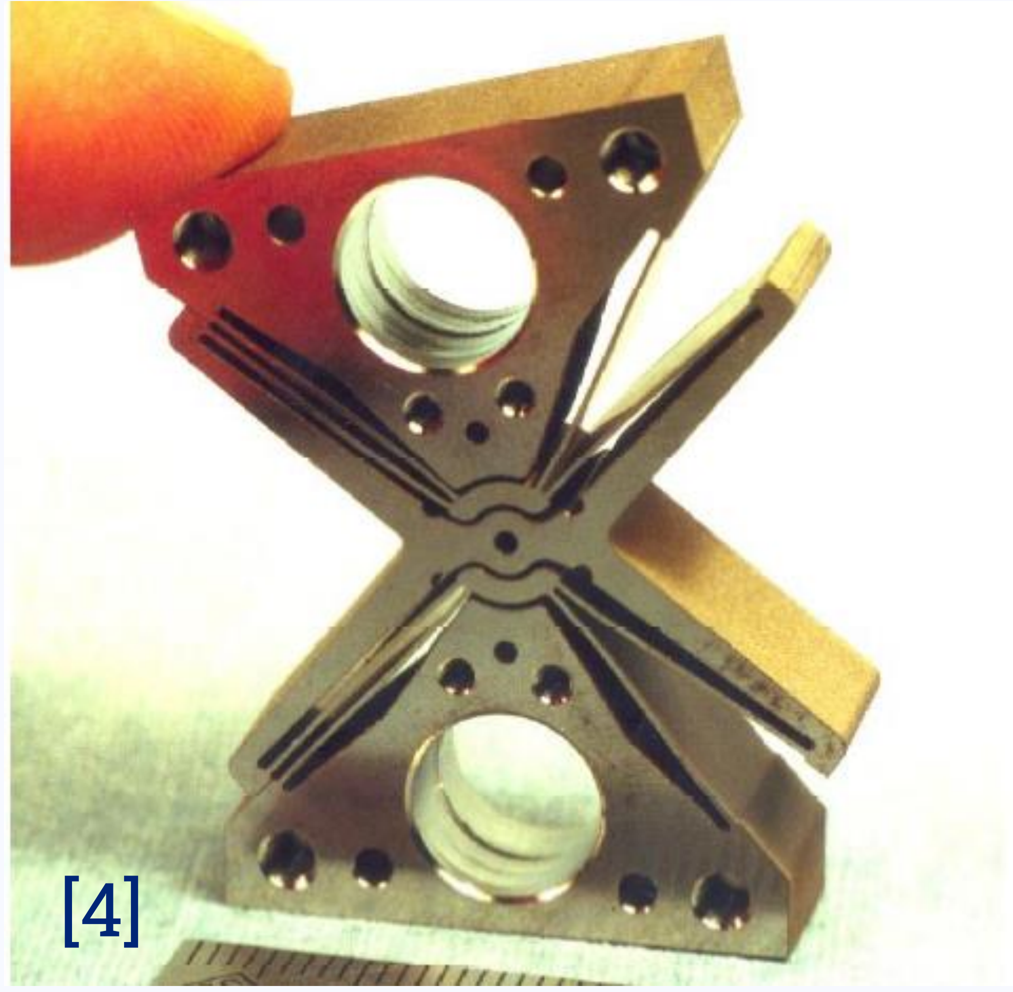
Manufacturing of Flexible Parallel Robots

Smart Composite Microstructures



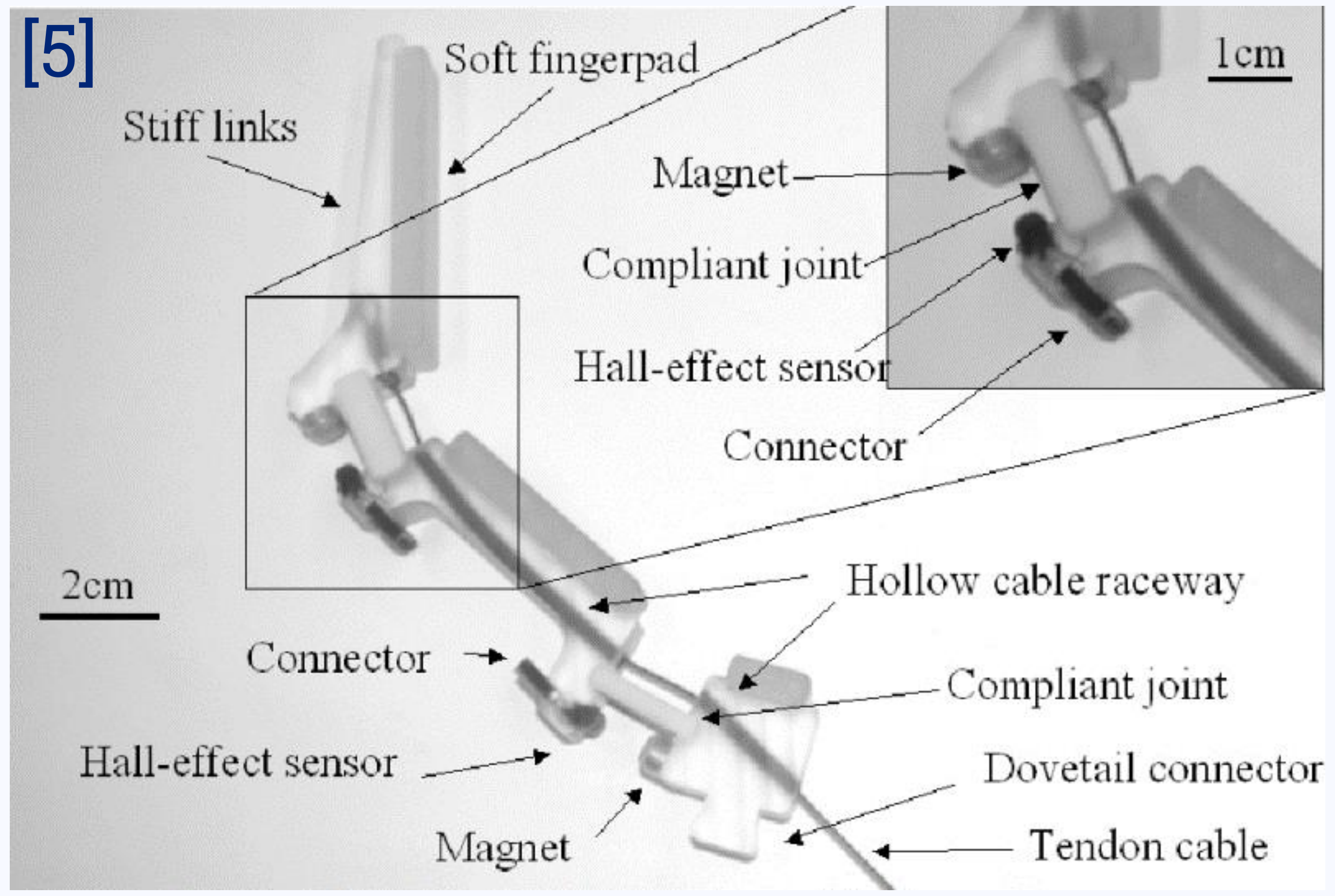
Laminated composites
"***cut-and-fold***" approach
Nylon with carbon fibre, stiff cardboard
Applications: Surgery, Haptics

Electric Discharge Machining



Metallic materials
"***butterfly***" hinge
Applications: Aerospace, Hexapods

Shape Deposition Manufacturing



Locally tuning material properties
Multistep moulding
Applications: Robot hands

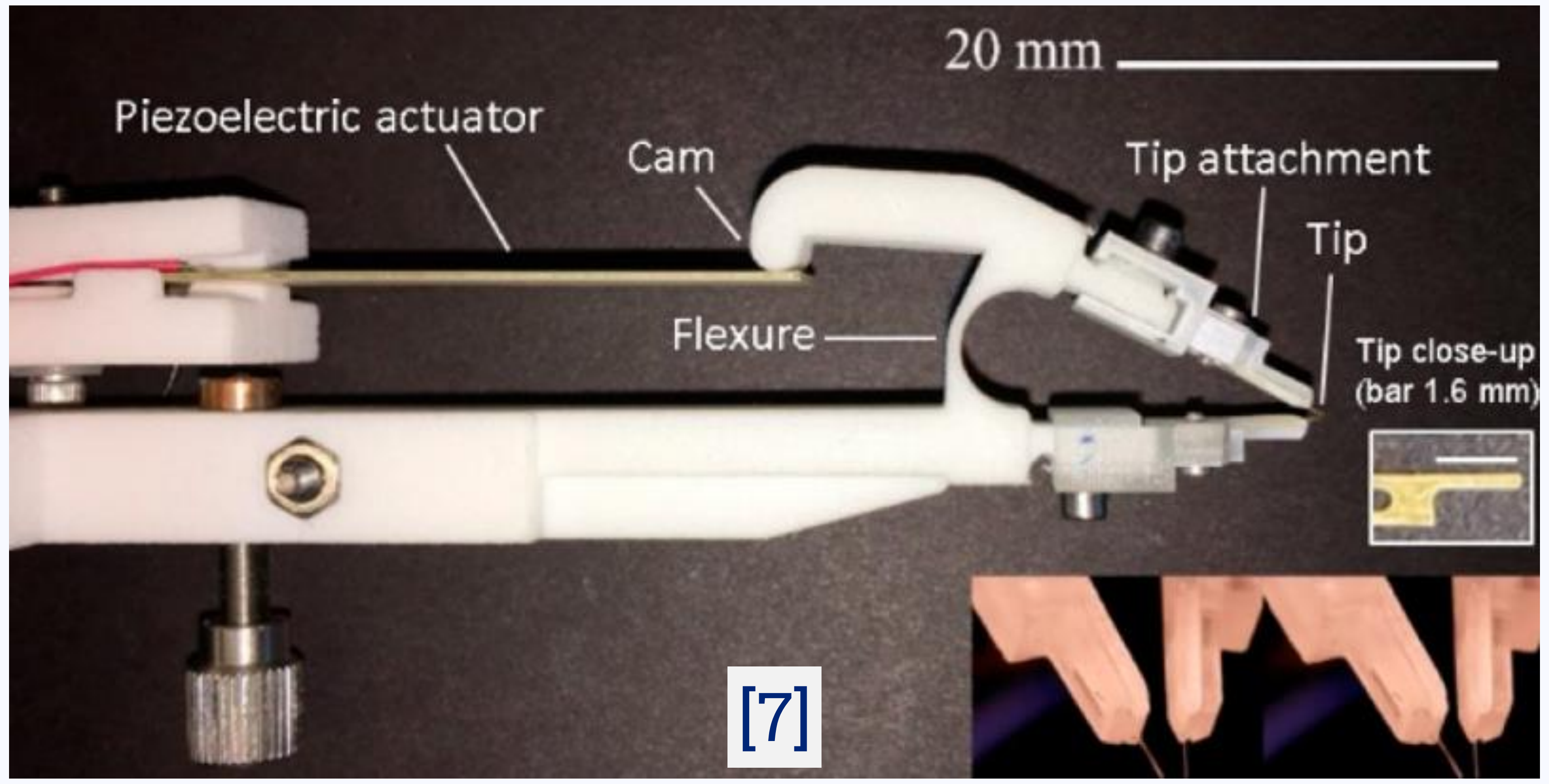
[2] McClintock *et. al.*; Sci. Robotics 2018
[3] Mintchev *et. al.*; Nature M.I. 2019
[4] Henien *et. al.*; 2003
[5] Dollar *et. al.*; T-MECH. 2006

Compliant Robots in Plastic

Fused Filament Fabrication

Applications:
Miniature microscope

Selective Laser Sintering



Applications:
Robotic microtweezers

Advantages

- Less constrained to geometries
- More tolerant to strain
- Simpler
- Affordable

Nylon Properties

- Low Young's Modulus
- Good Flexibility
- Resistance to stiffness ratio

[6] Sharkey et. al.; Review of Sci. Inst. 2016

[7] Almeida *et. al.*; Micromachines 2019

2. Mechanism Description

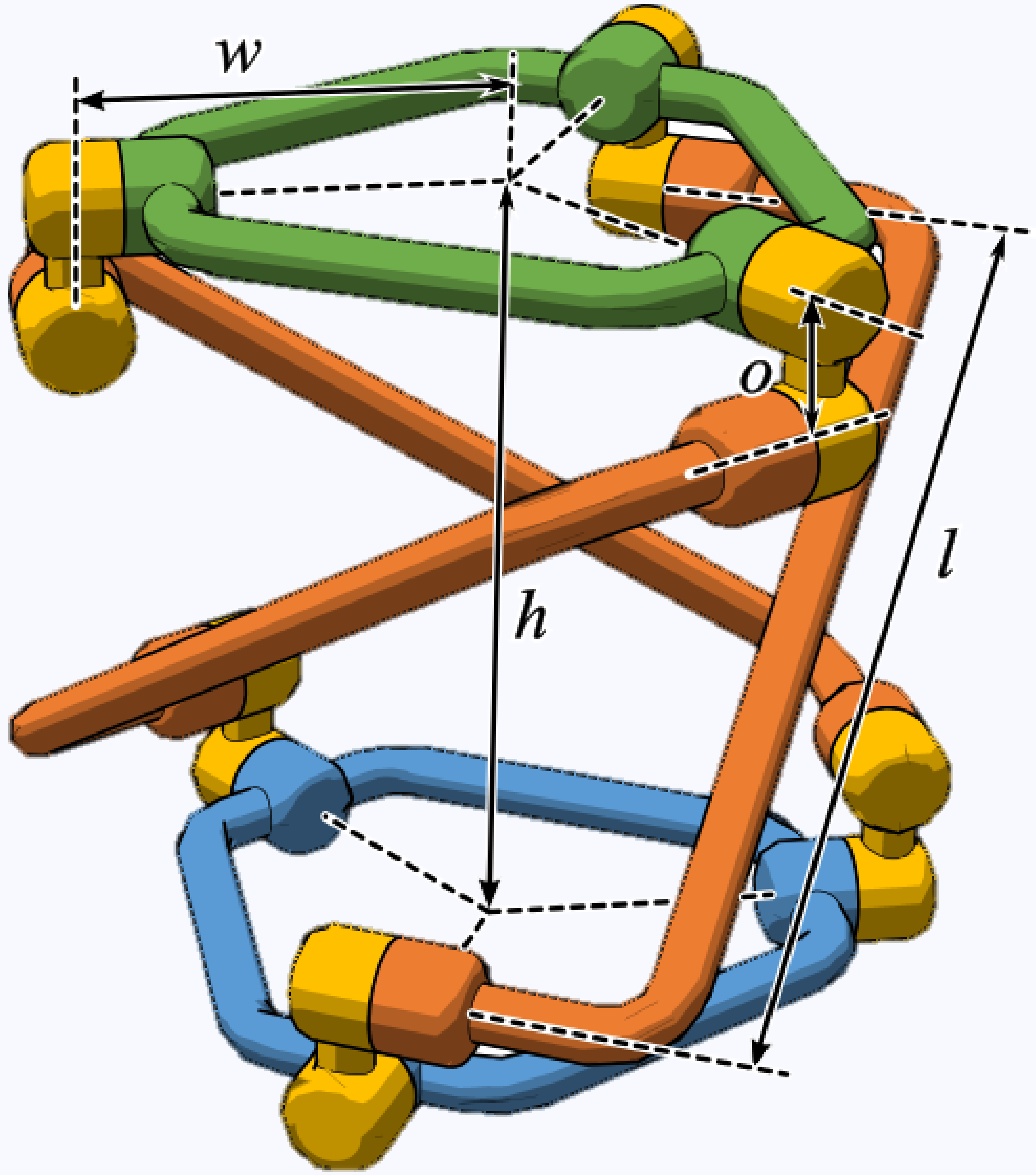
2 DOF Parallel Orientational Mechanism (2DPOM)

Kinematic Architecture

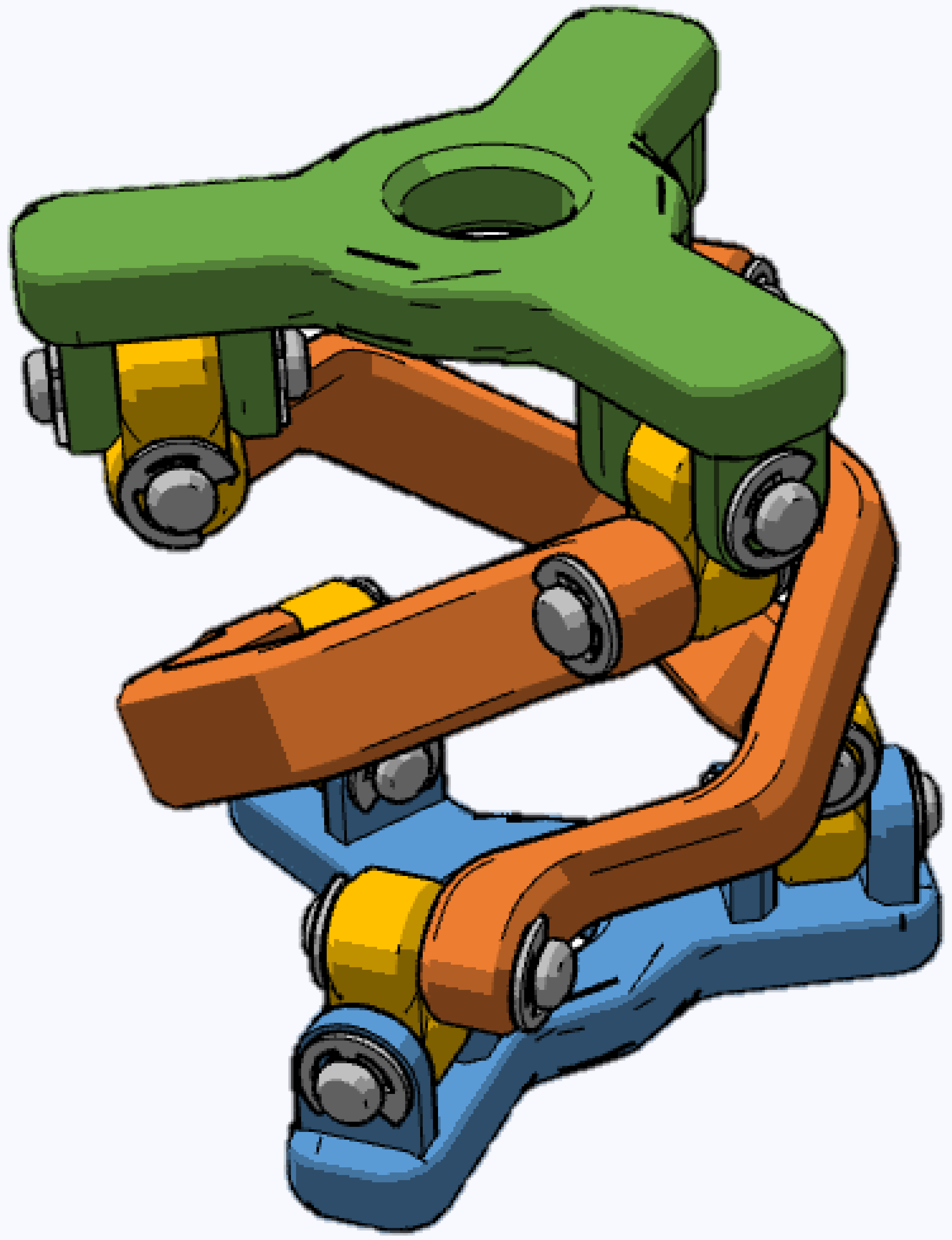
- Inspired from **Quaternion joint**[8] mechanism
- Anti-parallelogram structure
- Emulates rolling contact motion of two spheres

Geometric Parameters[9]:

- $o = 6\ mm$
  Offset between two axes of universal joint
- $w = 19\ mm$
  Radial distance from the torsional axis
- $l = 45\ mm$
  Length of the connecting link
- $h = \sqrt{l^2 - (2w)^2} + 2o$
  Height of platform centre from base centre



Traditional vs Flexible Models

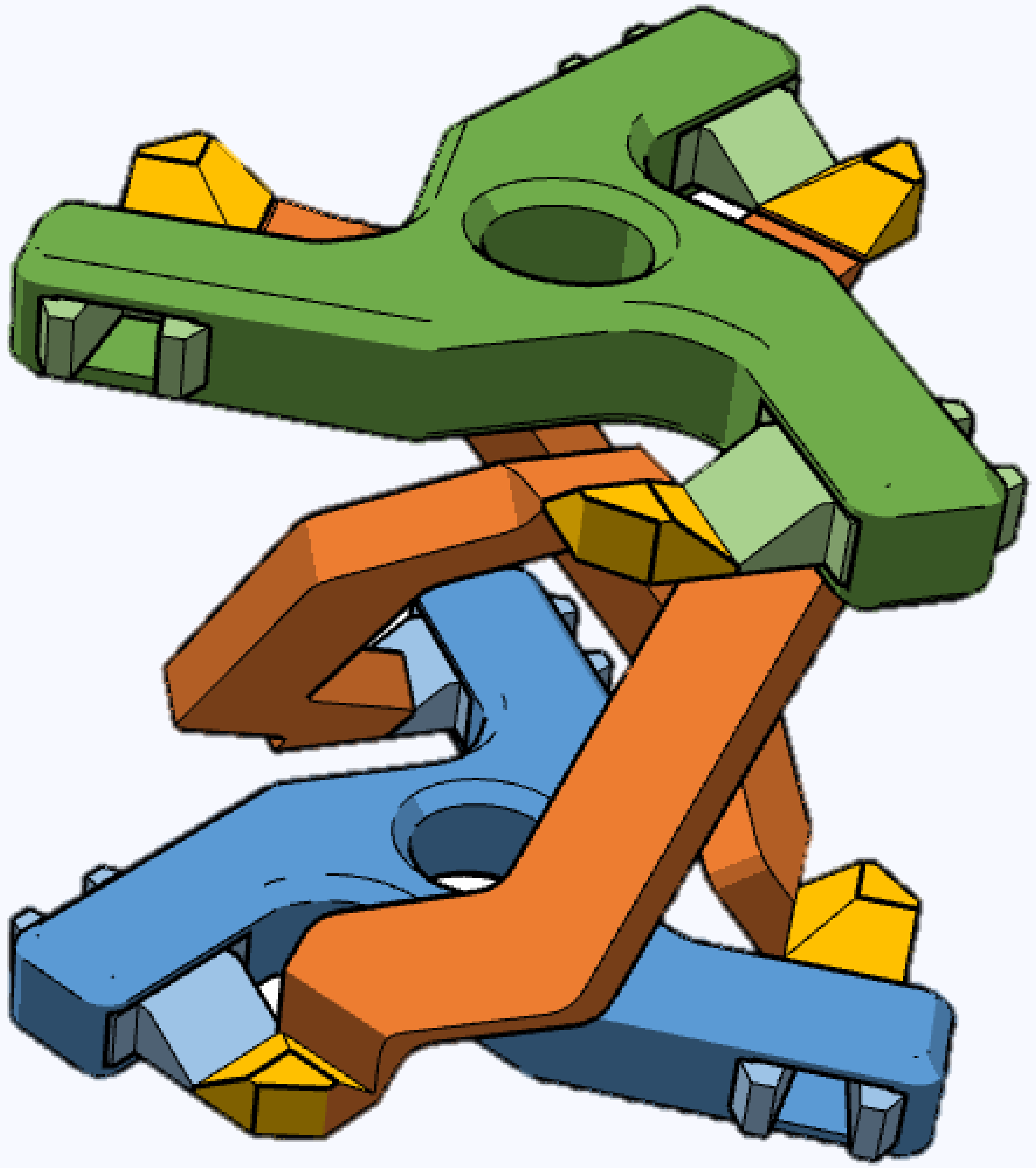


Traditional

- Rigid links
- Connecting pins as joints
- ***11 parts***

Flexible

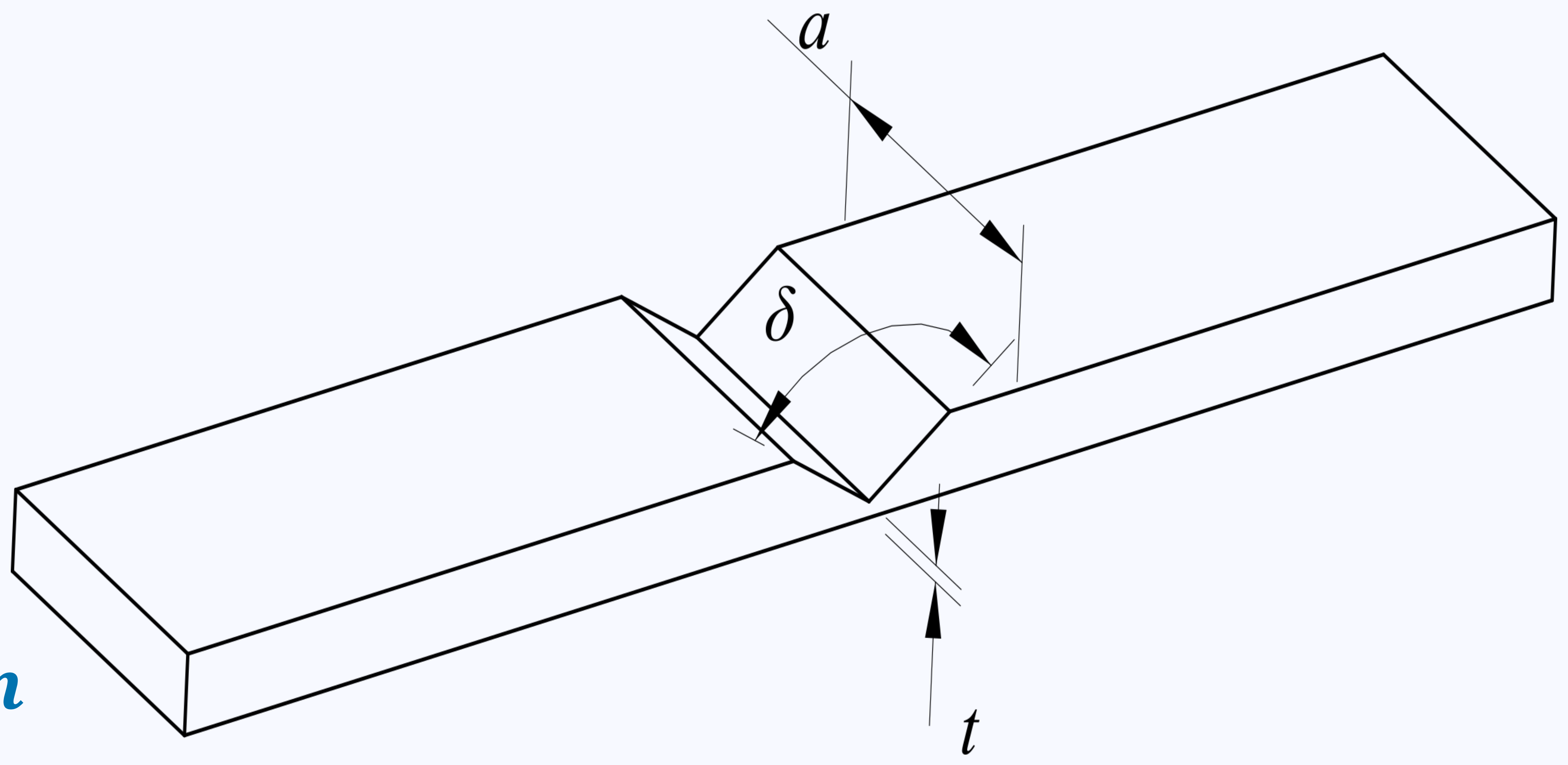
- Flexure hinges
- ***5 parts***



3. Flexure Design

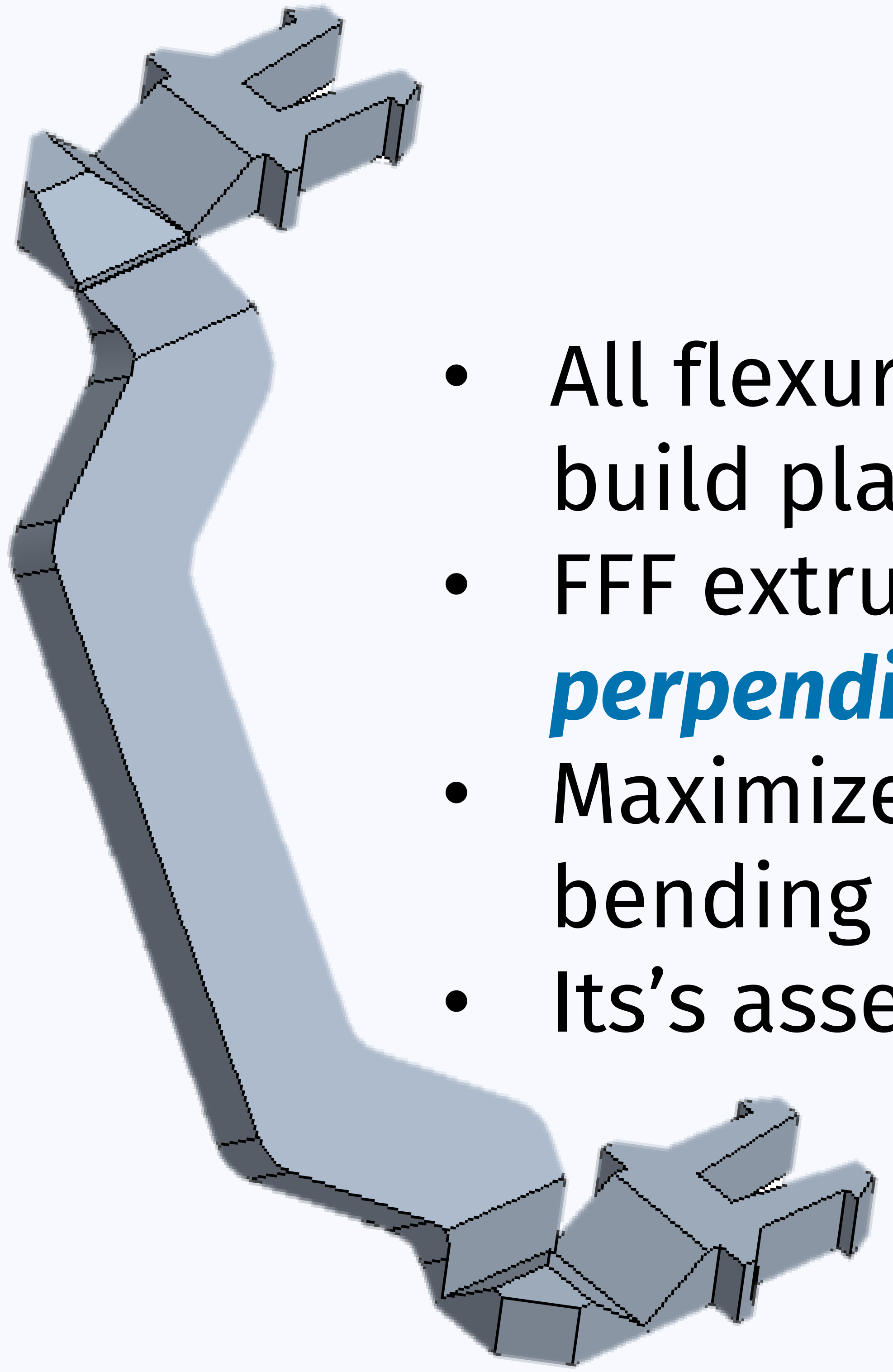
Flexible Model Design & Fabrication

Flexure Design



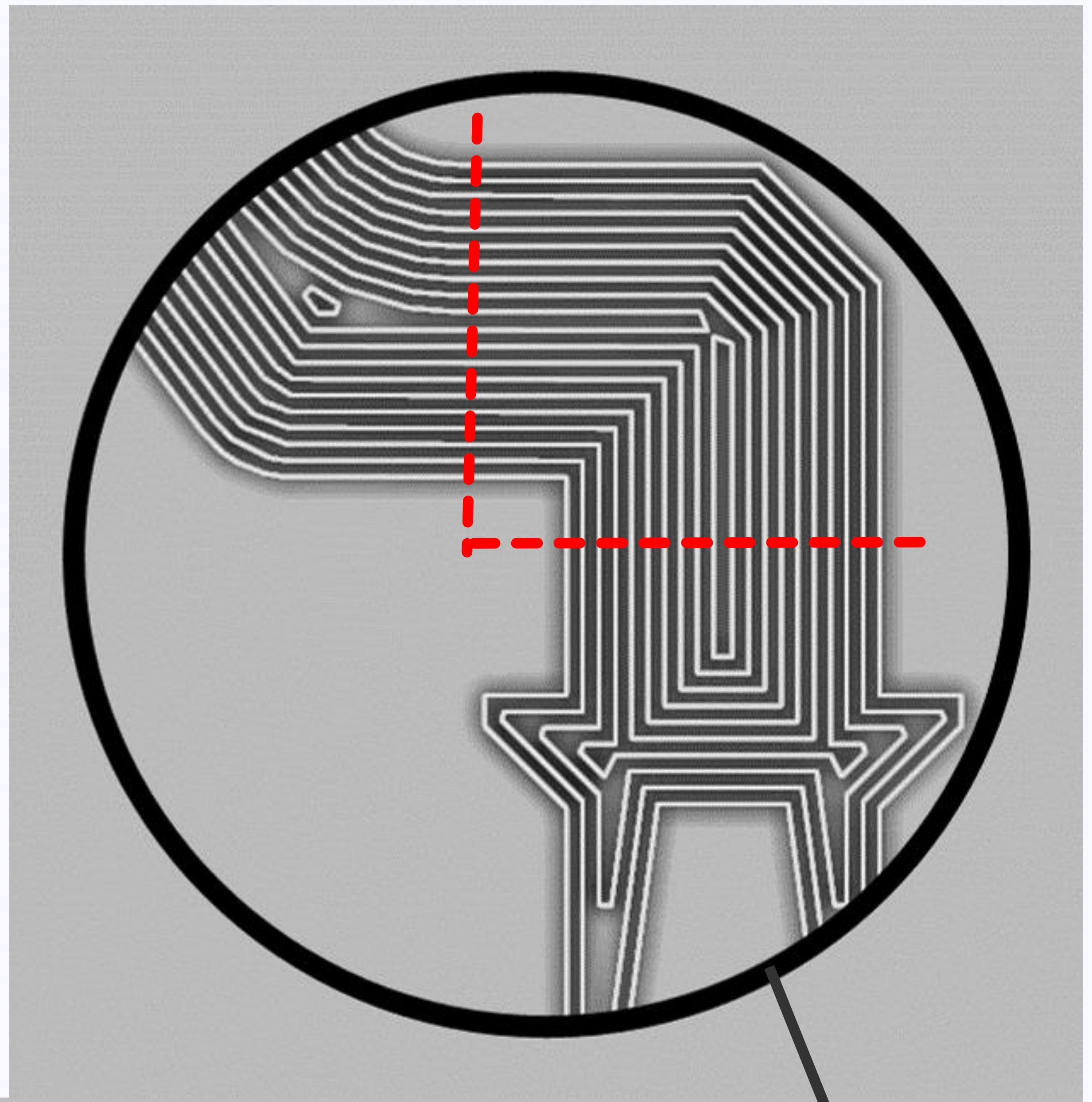
Geometric Parameters

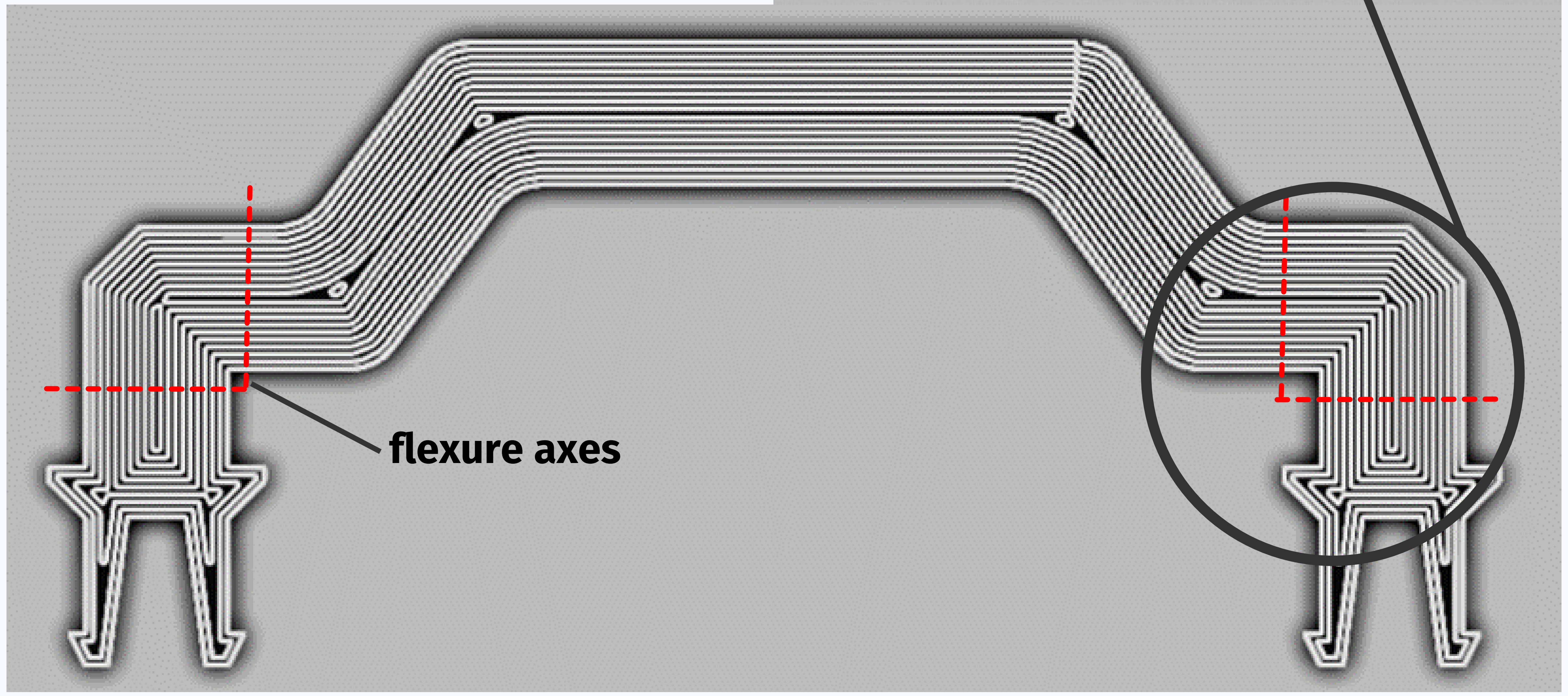
- Notch angle $\delta = 100°$
- Flexure width $a = 4\ mm$
- Flexure thickness $t = 0.5\ mm$



Build Strategy

- All flexure axes should be ***parallel*** to build plane
- FFF extruder paths are set to be ***perpendicular*** to the flexure axes
- Maximizes flexure's resistance to bending
- Its's assembled in zero configuration





Prototypes

Traditional- Selective Laser Sintering (SLS) Flexible- Fused Filament Fabrication (FFF)

Same material- ***Nylon (Polyamide 12)***

4. Experimental Validation

Comparing the Traditional & Flexible Models

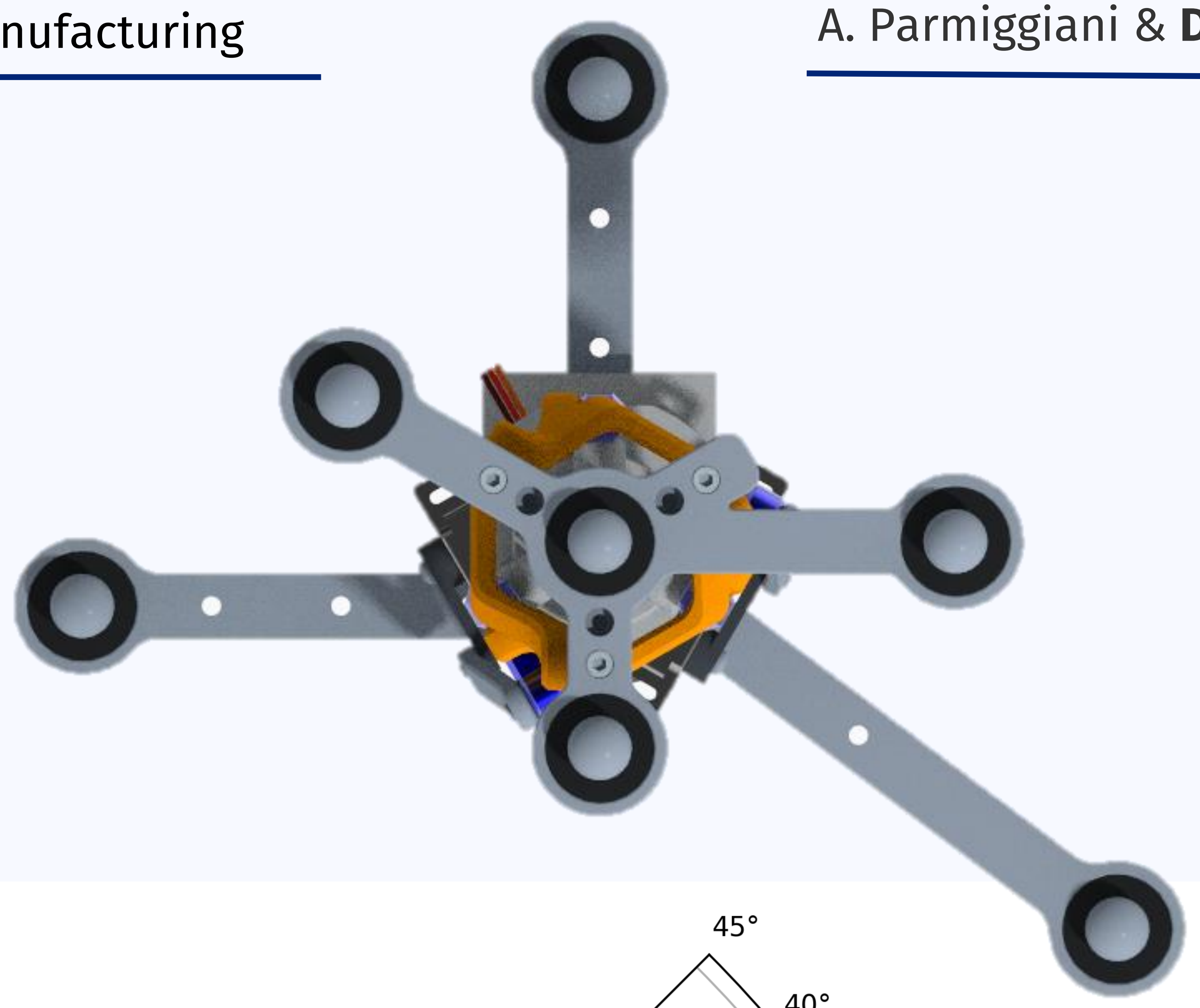
Backlash Assessment

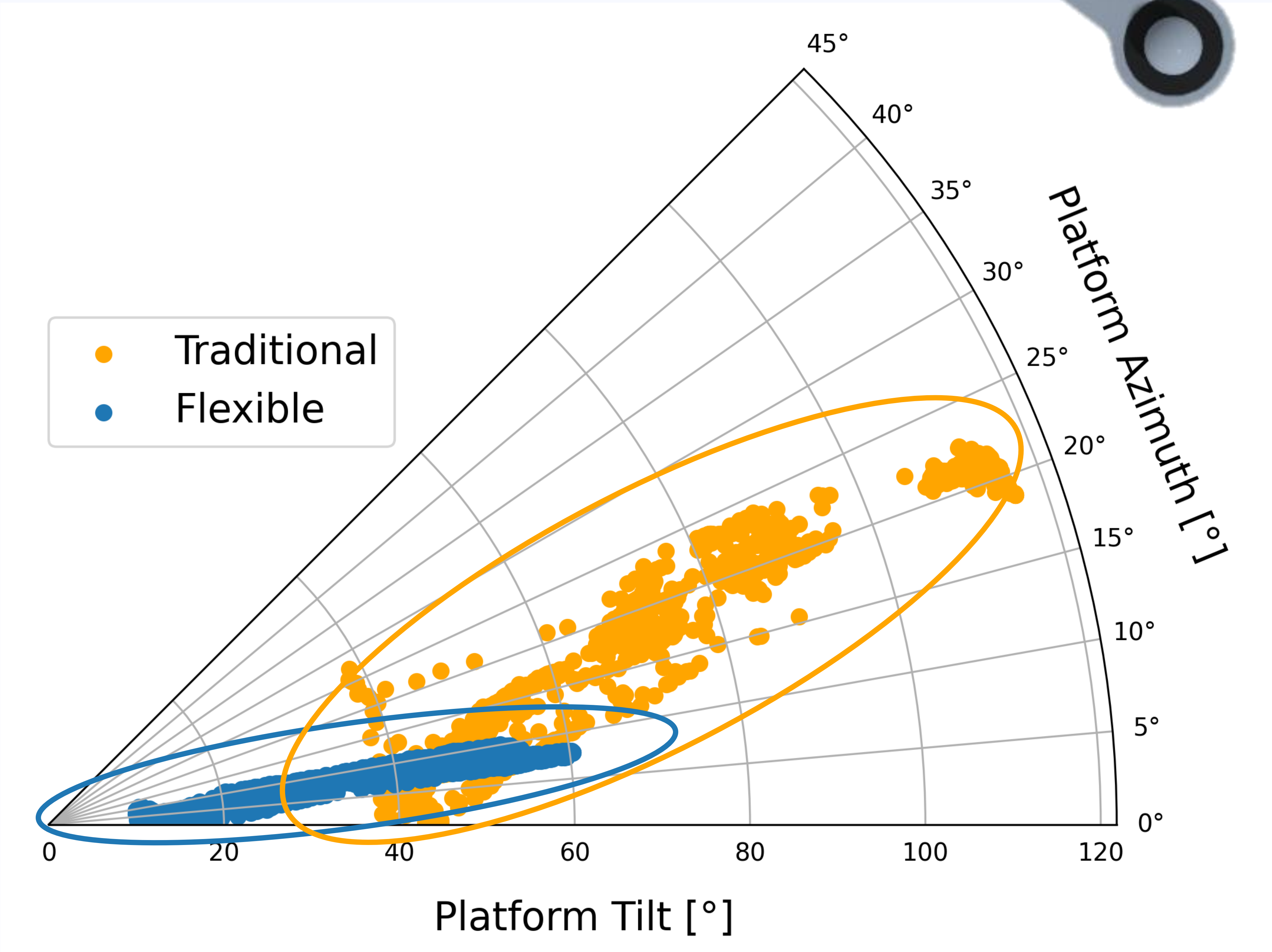
- *Vicon Vantage* motion capture system
- Attached markers to base and platform

- Repeated platform motion from **zero configuration** to **maximum tilt**
- Platform Orientations extracted from motion capture

- Motion of traditional model is more scattered than flexible model

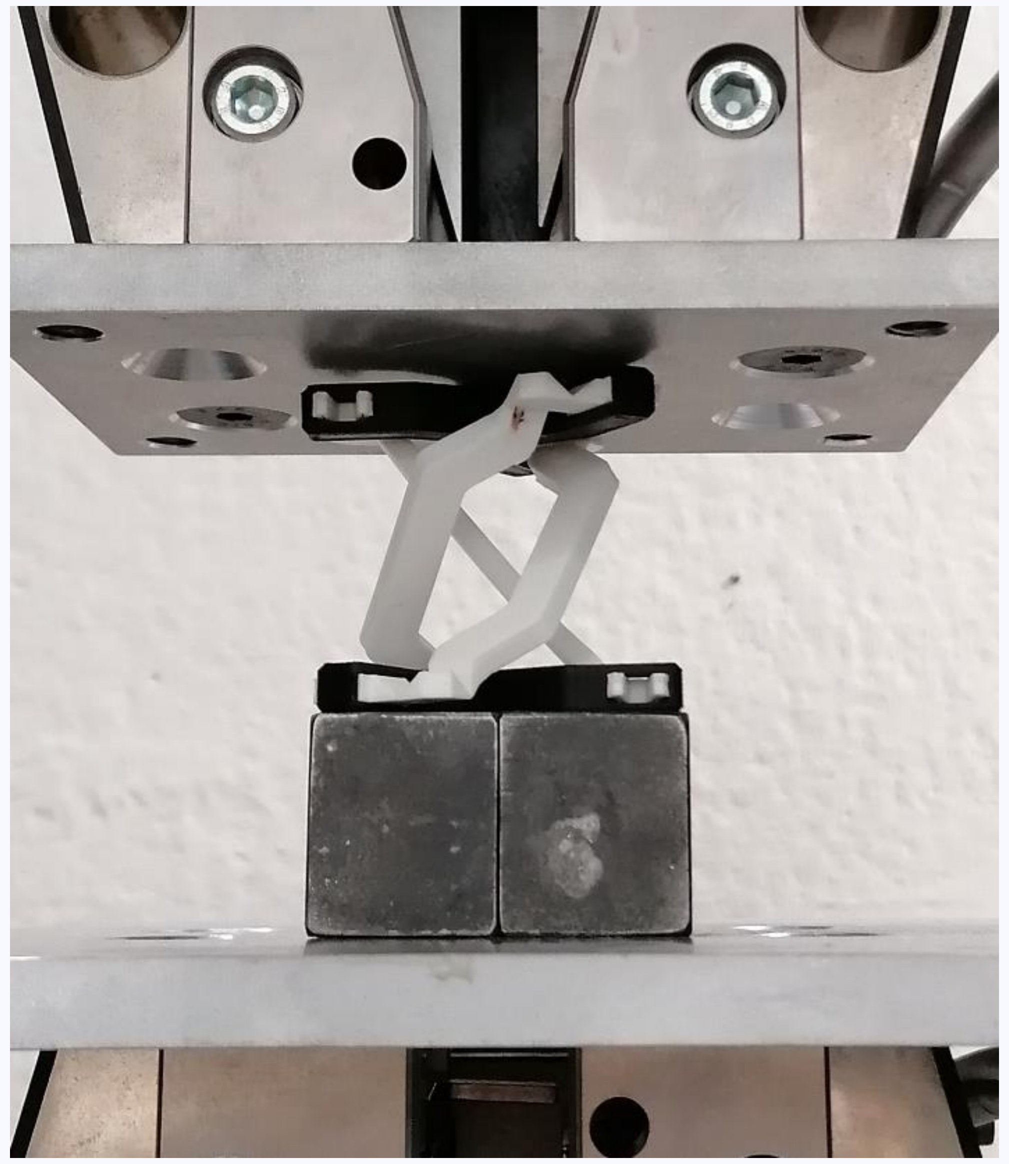
- More scattered → **Higher backlash!**

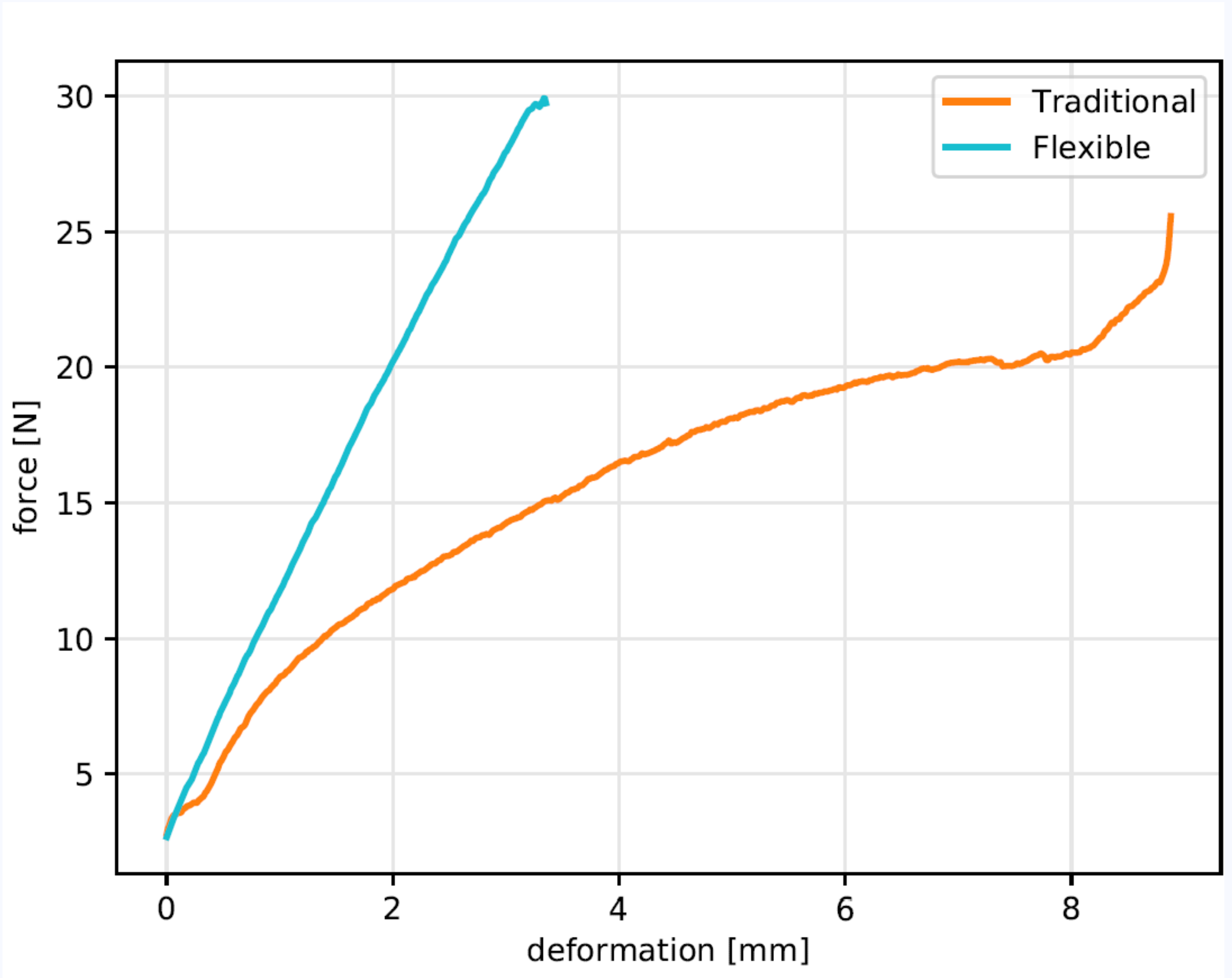


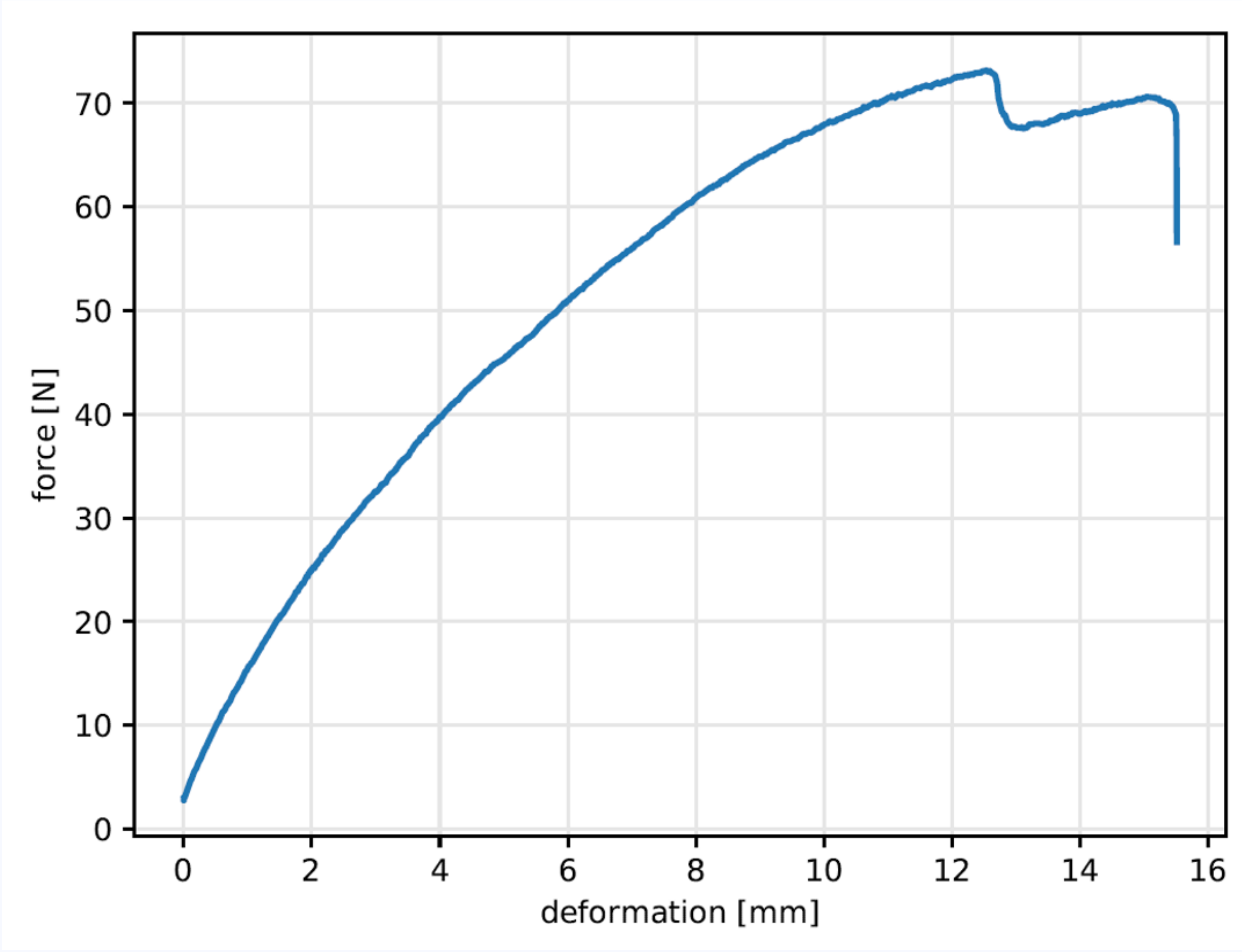


Loading Test

- *Zwick-Roell ProLine* testing machine
- Compressed gradually to **30 *N***, with cross-bar speed of **5 *mm/min***
- At **8.5 *mm*** traditional model self-collides
- Flexible model can withstand up to **70 *N*** before breaking 👍
- Failure occurs at the first flexure







5. Conclusions

Summary & Outlook

Conclusions

Small-scale flexible parallel robots are

- ***Easier to manufacture and assemble***
- ***Less mechanical backlash***
- Withstand sufficient loads for small-scale applications
- ***FFF*** using ***Nylon (Polyamide 12)*** is suitable for flexure hinges

Future Work

- Evaluating flexure's ***fatigue life*** as a function of applied loads and number of loading cycles
- Optimizing mechanism geometry considering flexure parameters
- Expanding the study to different classes of parallel mechanisms

Thank You!!!

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Rethinking Robot Design via Additive Manufacturing

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Fin!