Enhancing In-hand Manipulation via Mechanical Intelligence

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Manipulation



Intentional physical changes to the environment

Gross manipulation

"Forge-Blacksmith-Hammer-Iron-Fire" by TiBine / CC0 1.0 (Cropped from original), "A Navy family unloads…" by Michael W. Pendergrass / Public Domain Mark 1.0 (Cropped from original), "Kayaking" by skeeze / CC0 1.0 (Cropped from original)

Coordination of large body parts and/or movements

Fine manipulation

Coordination of small body parts and/or movements

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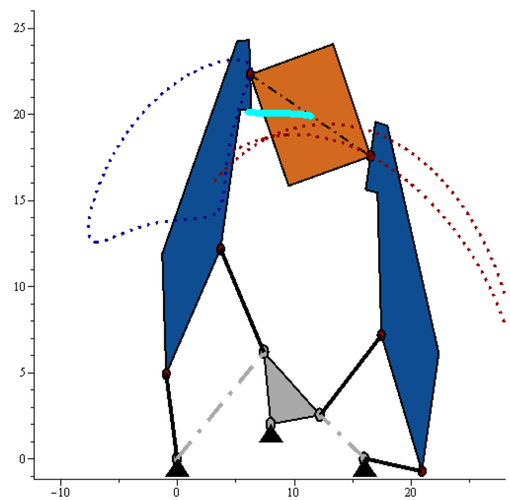
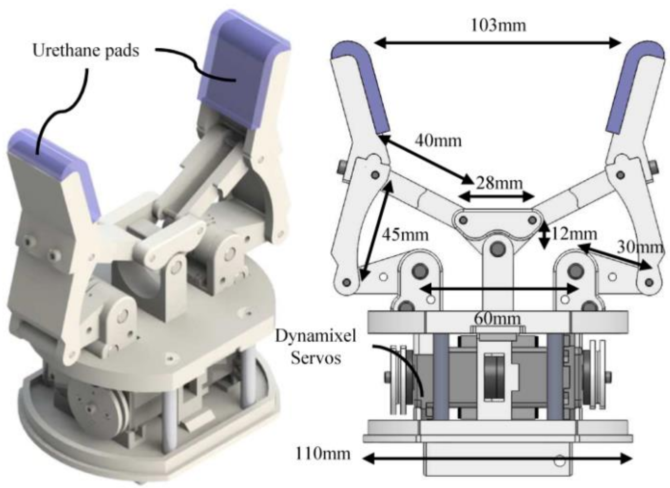
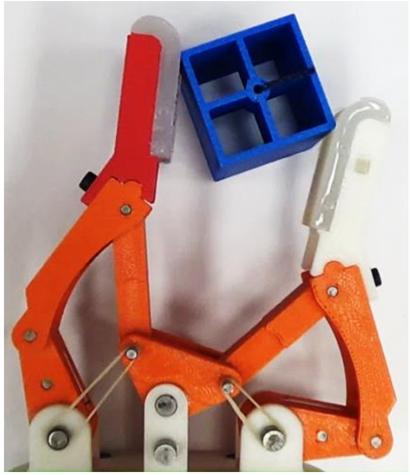
Robotic Manipulation: Engineering, Design, and Science Laboratory







Research focused on the analysis, design, and implementation of robotic systems that can purposefully perform physical changes to the world around us

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Key points

- Broad research interests:

  Robotic gross manipulation

  Robotic fine manipulation

New manipulator and end effector concepts and technologies

- Research principles:

  Theoretical and practical

- Long-term goal:

  Create robots from scratch that surpass the manipulation capabilities observed in humans and other animals under diversity and uncertainty

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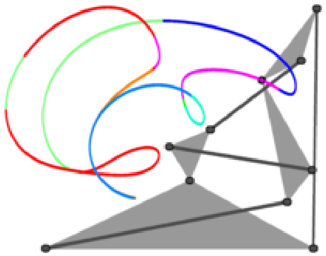
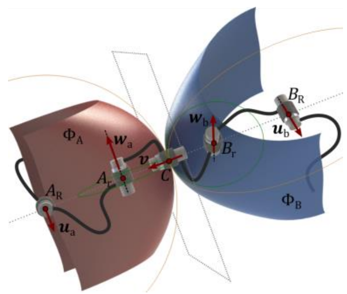
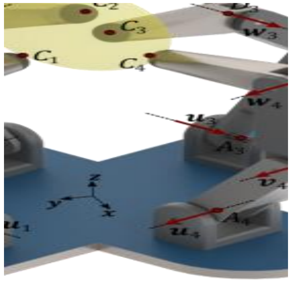
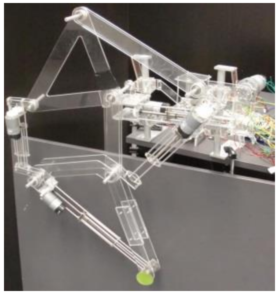
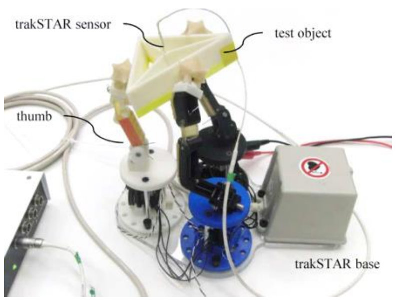
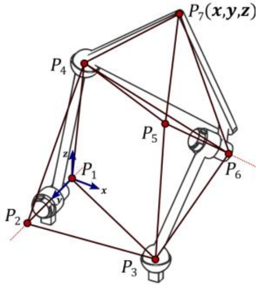
Current research areas

Biomechanics of the human hand
Contact modelling and characterisation
Compliant robot mechanisms
Dexterous manipulation
Distance-based computational kinematics
Flexible manipulators
In-hand manipulation analysis and planning
Mechanically-intelligent robot manipulators and hands
Parallel robots architectures
Reconfigurable robotic systems
Underactuated robot hands

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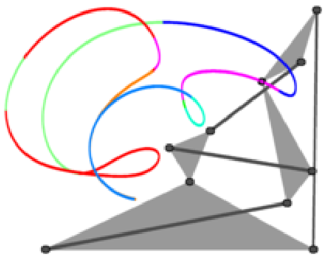
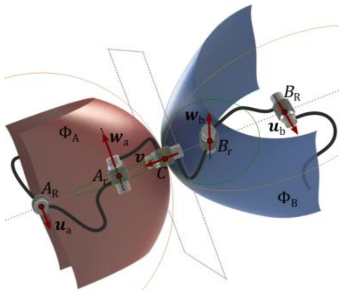
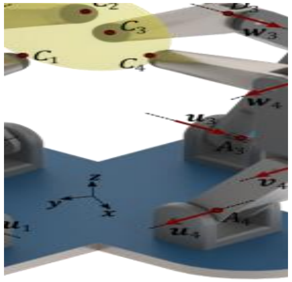
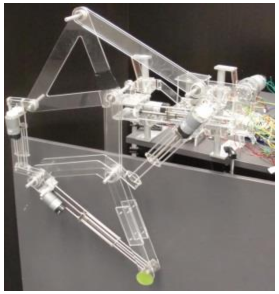
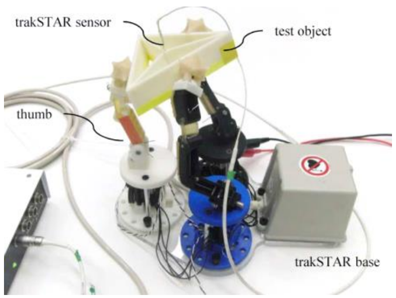
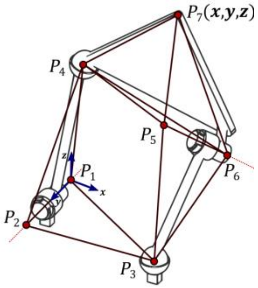
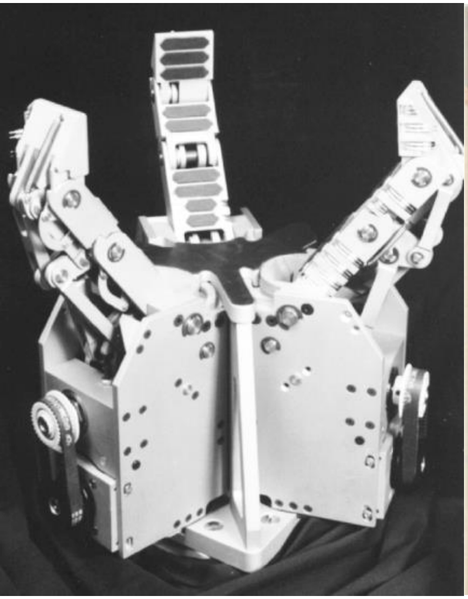



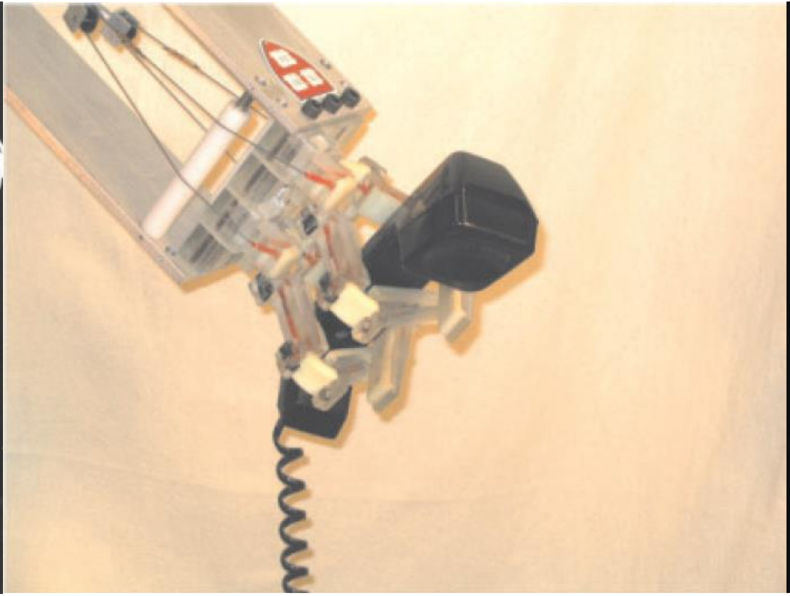




Underactuated hands



The MARS Hand (C. Gosselin and T. Laliberte, US Patent 1996)



The SDM Hand (A.M. Dollar and R.D. Howe, IJRR 2010)

The Velo Gripper (M. Ciocarlie et al., IJRR 2014)

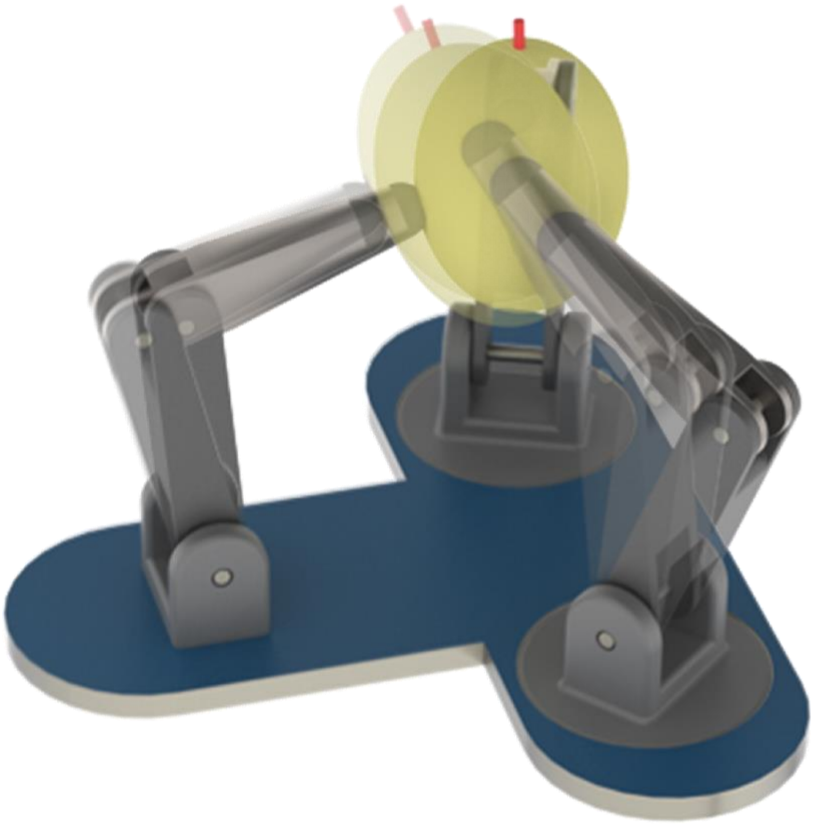
Underactuated fingers can produce passively adaptive grasps with minimal control and hardware complexity

Underactuated hands

Yale OpenHand Model T
(R.R. Ma et al., ICRA 2013)

Dexterous manipulation certainly remains a difficult task even for complex, redundantly-actuated hands

In-hand manipulation

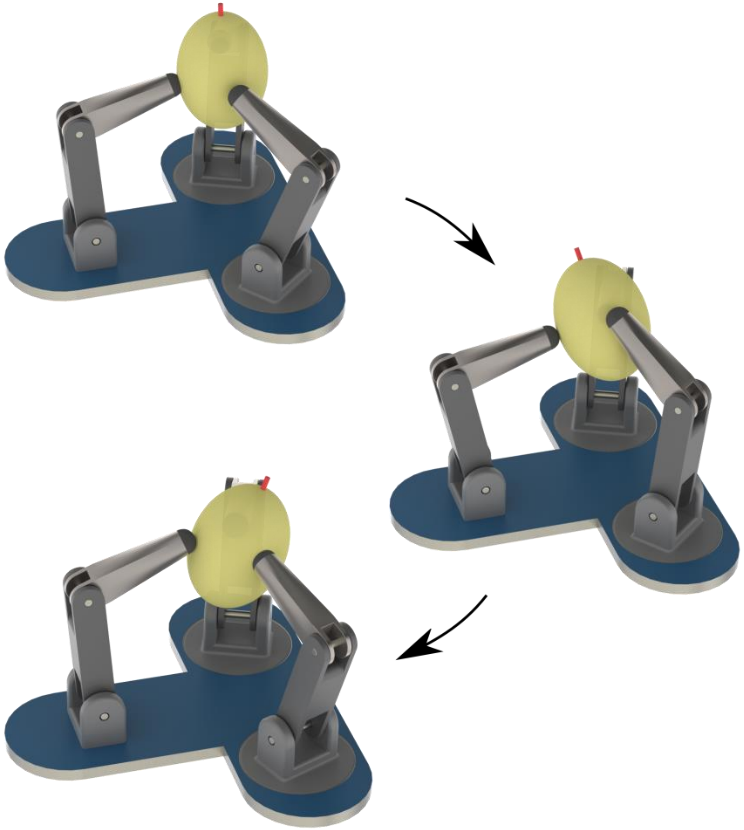


Dexterous in-hand manipulation extends the utility of hands to beyond just acquiring and maintaining grasps

Solutions for Enhancing In-Hand Manipulation Capabilities

- Extrinsic dexterity

- Intrinsic dexterity



Solutions for Enhancing In-Hand Manipulation Capabilities

Extrinsic dexterity

Manipulation of an object in the hand using resources extrinsic to the hand (e.g. an edge, gravity)

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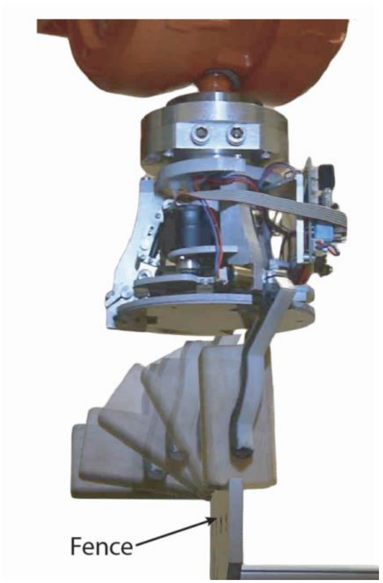
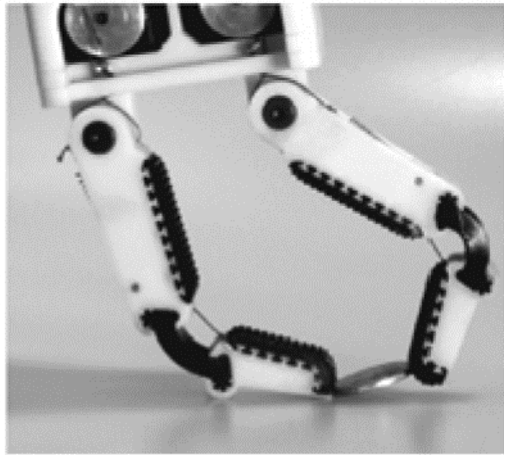
In-hand regrasping or

Caging manipulation

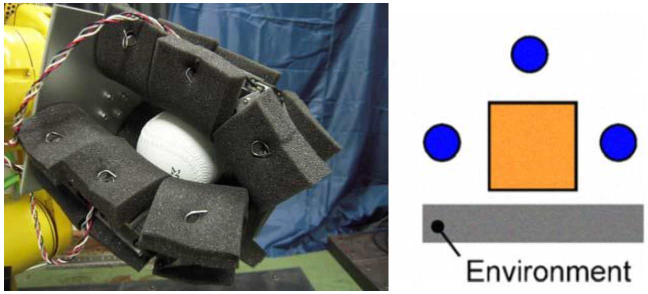


(N. Chavan-Dafle et al., ICRA 2014)



(L. U. Odhner, R. R. Ma, and A. M. Dollar, T-ASE 2013)

(N. Chavan-Dafle et al., CASE 2015)



(R. Yokoi, T. Kobayashi, and Y. Maeda, ISAM 2009)
(Y. Maeda, N. Kodera, and T. Egawa, ICRA 2012)

(Eppner et al., IJRR 2015)

Solutions for Enhancing In-Hand Manipulation Capabilities
Intrinsic dexterity

Manipulation of an object in the hand applying forces to the object through the fingertips

↓

Dexterous manipulation

Solutions for Enhancing In-Hand Manipulation Capabilities

Intrinsic dexterity

Manipulation of an object in the hand applying forces to the object through the fingertips

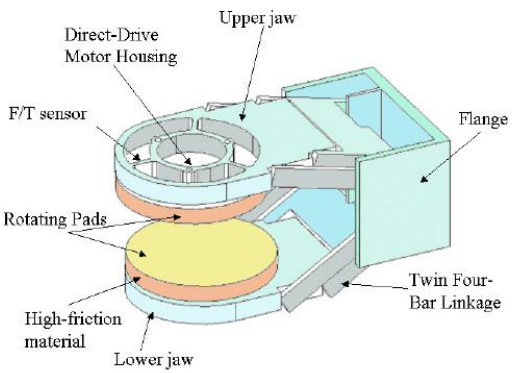
- High-fidelity contact sensors
- Active/sliding fingertips (surfaces)
- A priori workspace exploration

Solutions for Enhancing In-Hand Manipulation Capabilities

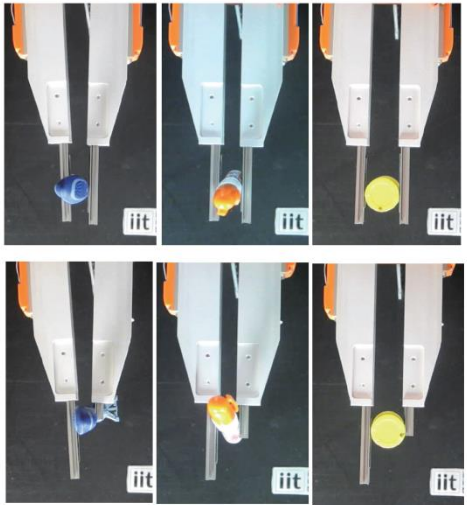
Intrinsic dexterity

Manipulation of an object in the hand applying forces to the object through the fingertips

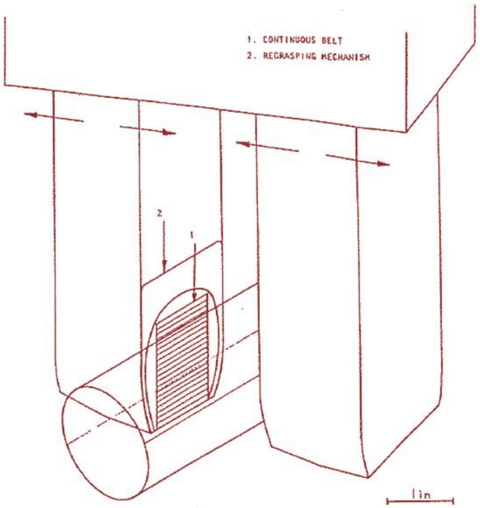
- High-fidelity contact sensors
- Active/sliding fingertips (surfaces)
- A priori workspace exploration



(A. Bicchi and A. Marigo, IJRR 2002)

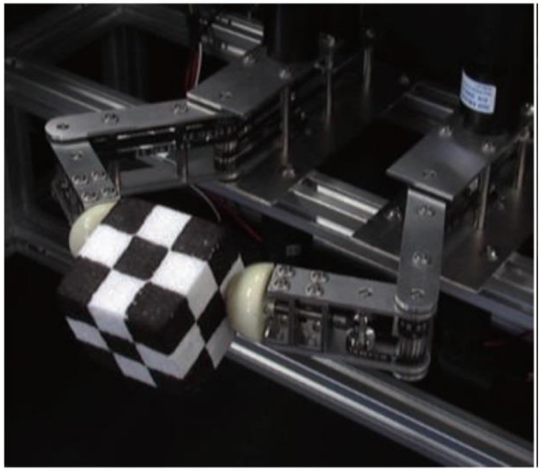


(F. Chen et al., ICRA 2014)

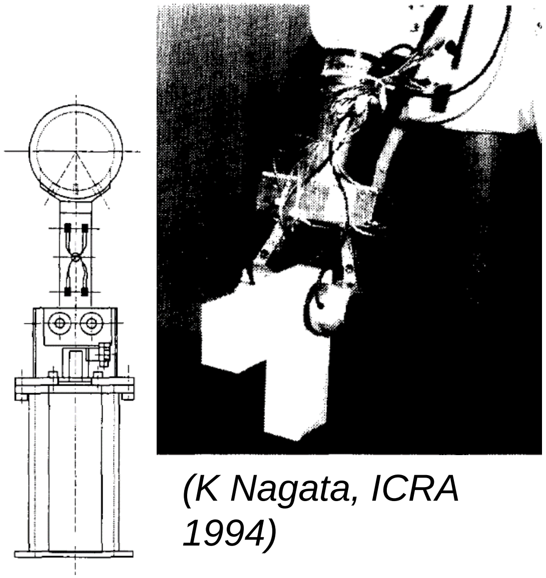


(P. Datseris and W. Palm, ASME JMTAD 1985)

(V. Tincani et al., ICRA 2013)



(K. Tahara, K. Maruta, and M. Yamamoto, ICRA 2010)



(K Nagata, ICRA 1994)

Our approach

A novel *intrinsic dexterity* approach based on flexible and adaptive mechanical components generating predictable behaviours of the hand-object system

Contact modelling	Manipulation analysis	Design of robot hands

Our approach

A novel *intrinsic dexterity* approach based on flexible and adaptive mechanical components generating predictable behaviours of the hand-object system

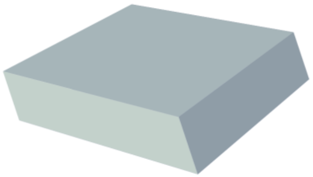
Contact modelling

Manipulation analysis

Design of robot hands

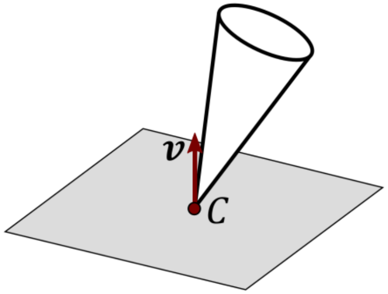
Contact modelling

The types of contact interactions which can occur between a grasped object and a fingertip are usually classified in nine categories

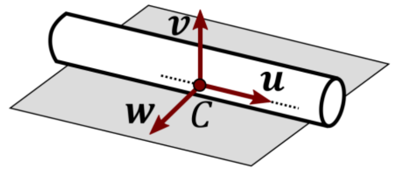


No contact
(6 Degrees of Freedom)

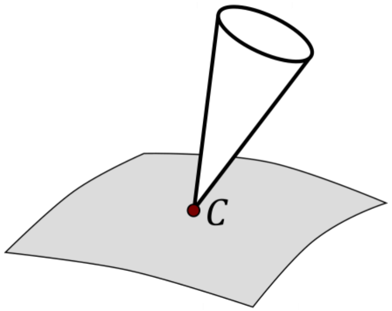
Contact modelling



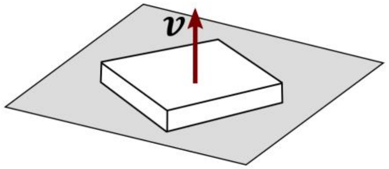
Point contact
without friction (5)



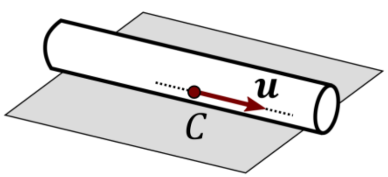
Line contact
without friction (4)



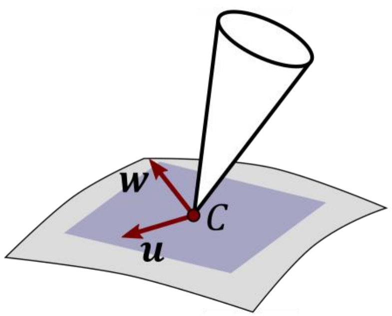
Point contact
with friction (3)



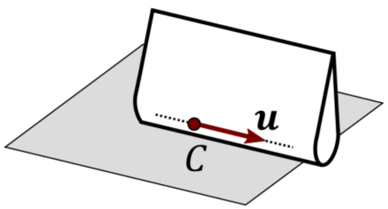
Planar contact
without friction (3)



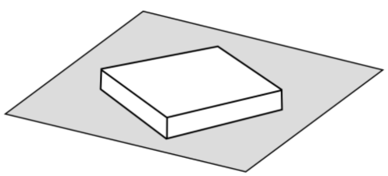
Line-line contact
without friction (2)



Soft finger (2)

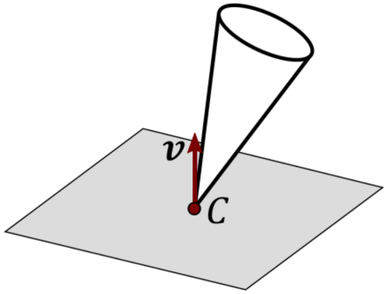


Line(-line) contact
with friction (1)

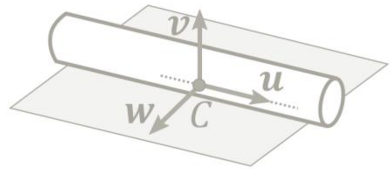


Planar contact
with friction (0)

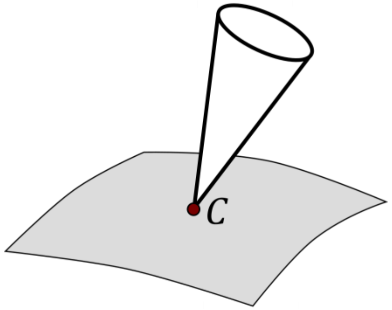
Contact modelling



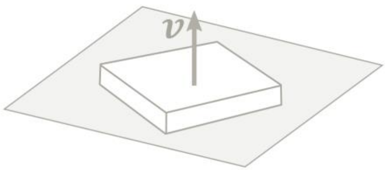
Point contact without friction (5)



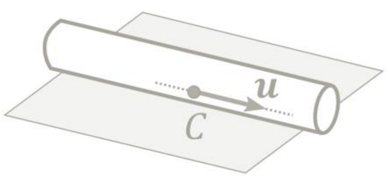
Line contact without friction (4)



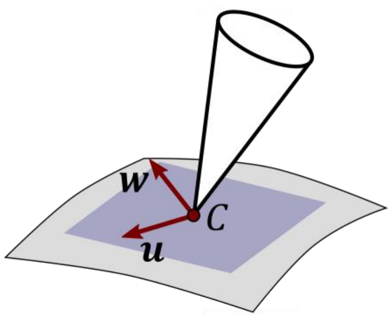
Point contact with friction (3)



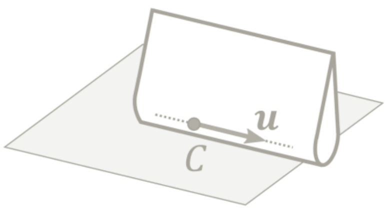
Planar contact without friction (3)



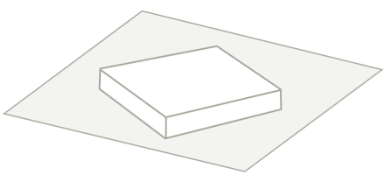
Line-line contact without friction (2)



Soft finger (2)



Line(-line) contact with friction (1)



Planar contact with friction (0)

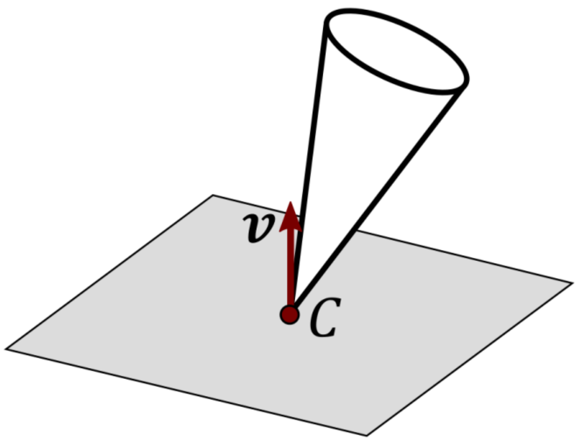
Contact modelling

Kinematic equivalents

A kinematic equivalent simply corresponds to a single kinematic constraint (a subset of the continuous group of displacements) that represents the constrained motion between two contacting bodies

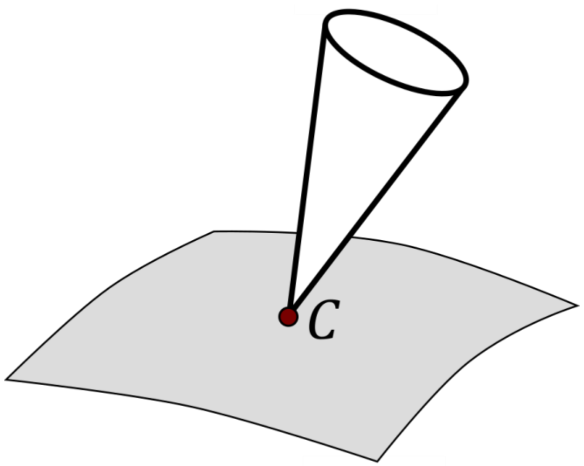
Contact modelling

Kinematic equivalents



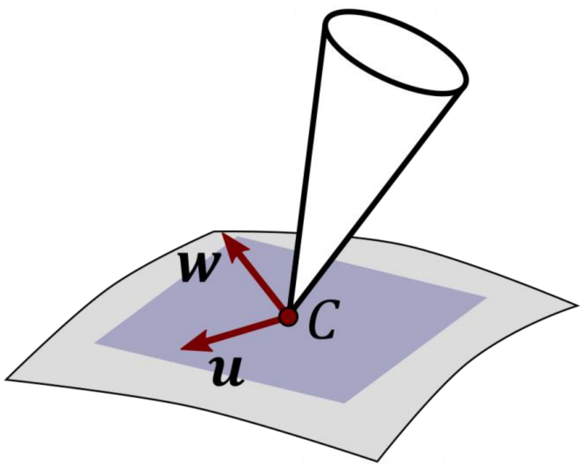
Point contact without friction

(Spherical+Planar joint)



Point contact with friction

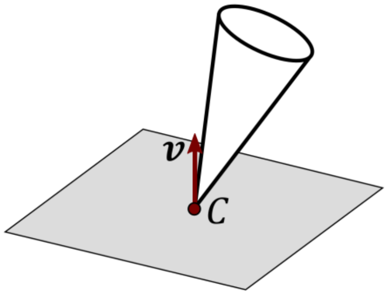
(Spherical joint)



Soft finger

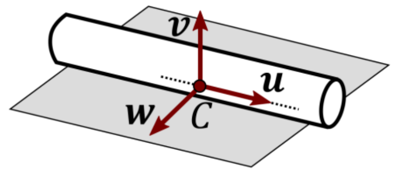
(Universal joint)

Contact modelling



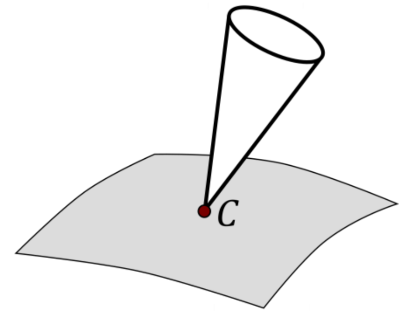
Point contact without friction (5)

$\{\mathbf{S}(C)\} \cdot \{\mathbf{P}(\boldsymbol{v})\}$



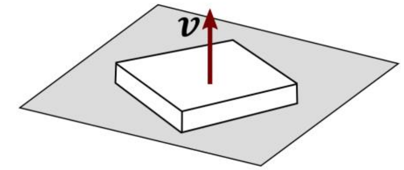
Line contact without friction (4)

$\{\mathbf{C}(C, \boldsymbol{u})\} \cdot \{\mathbf{R}(C, \boldsymbol{v})\} \cdot \{\mathbf{T}(\boldsymbol{w})\}$



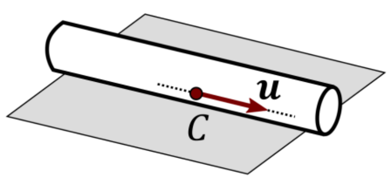
Point contact with friction (3)

$\{\mathbf{S}(C)\}$



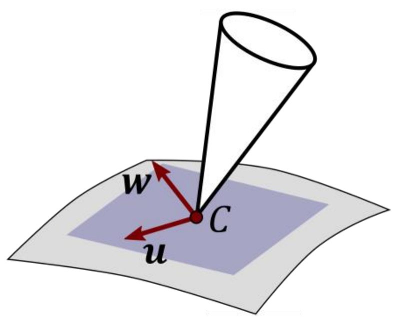
Planar contact without friction (3)

$\{\mathbf{G}(\boldsymbol{v})\}$



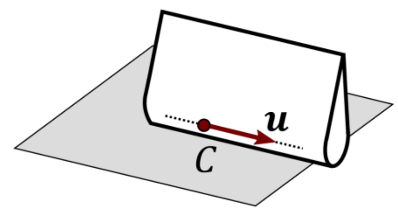
Line-line contact without friction (2)

$\{\mathbf{C}(C, \boldsymbol{u})\}$



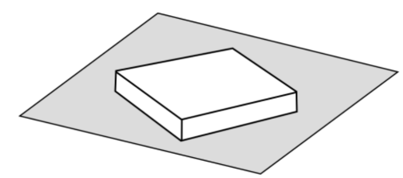
Soft finger (2)

$\{\mathbf{R}(C, \boldsymbol{u})\} \cdot \{\mathbf{R}(C, \boldsymbol{w})\}$



Line(-line) contact with friction (1)

$\{\mathbf{R}(C, \boldsymbol{u})\}$



Planar contact with friction (0)

$\{\mathbf{I}\}$

Contact modelling

All standard contact models used in robotic manipulation are based on modeling the effects of a finger contacting a body as a kinematic pair

Kinematic pairs

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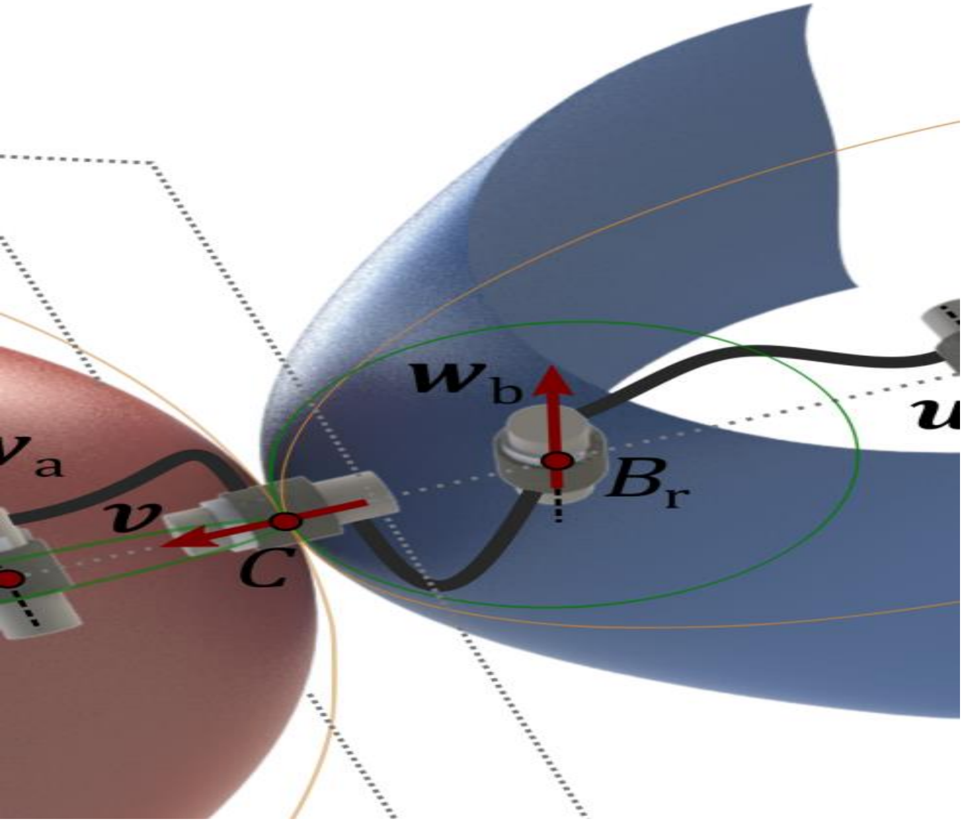
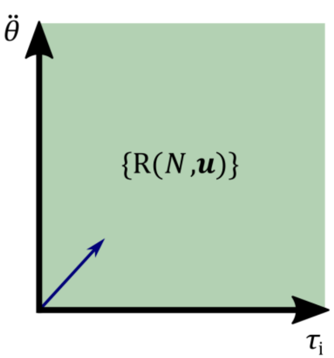
Kinematic chains

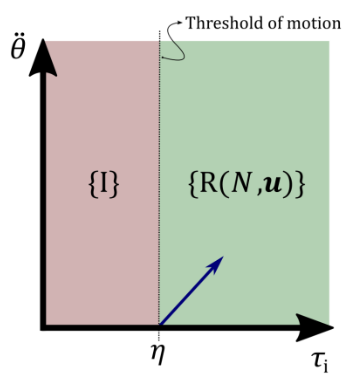
Natural generalization of the standard axiom



Kinematic-chain-based contact model based on an extension of the Bruyninckx-Hunt approach of surface-surface contact that uses the concept of resistant passive joints located in the object being manipulated



$\eta=0$
(Passive revolute joint)



$\eta>0$
(Resistant passive revolute joint)

$$\{\mathbf{R}(A_R,\boldsymbol{u}_\mathbf{a})\}\cdot\{\mathbf{R}(A_r,\boldsymbol{w}_\mathbf{a})\}\cdot\{\mathbf{R}(C,\boldsymbol{v})\}\cdot\{\mathbf{R}(B_r,\boldsymbol{w}_\mathbf{b})\}\cdot\{\mathbf{R}(B_R,\boldsymbol{u}_\mathbf{b})\}$$

N. Rojas and A.M. Dollar, "Classification and Kinematic Equivalents of Contact Types for Fingertip-Based Robot Hand Manipulation," ASME Journal of Mechanisms and Robotics (JMR), Vol. 8, No. 4, 041014 (9 pages), 2016

Contact type		Kinematic equivalent (Non-frictional/Frictional)	Special cases	
			Particular geometry*	**Limit instances****
Elliptic contact	$\mathcal{K}_{\Phi_A} > 0$	$\{\mathbf{R}(A_R, \boldsymbol{u}_\mathbf{a})\} \cdot \{\mathbf{R}(A_r, \boldsymbol{w}_\mathbf{a})\} \cdot \{\mathbf{R}(C, \boldsymbol{v})\} \cdot \{\mathbf{R}(B_r, \boldsymbol{w}_\mathbf{b})\} \cdot \{\mathbf{R}(B_R, \boldsymbol{u}_\mathbf{b})\}$ $(\eta_{B_r} = \eta_{B_R} = \eta_C = 0)$	Elliptic-ball contact, Elliptic-cylinder contact, Elliptic-plane contact, Non-frictional ball contact	Point-ball contact, Point-cylinder contact, Point-plane contact (or *(ii) Point contact without friction*), Ball-plane contact
		$\{\mathbf{R}(A_R, \boldsymbol{u}_\mathbf{a})\} \cdot \{\mathbf{R}(A_r, \boldsymbol{w}_\mathbf{a})\} \cdot \{\mathbf{R}(C, \boldsymbol{v})\}$ $(\eta_{B_r} > 0, \eta_{B_R} > 0, \eta_C = 0)$	Ball contact	*(iv) Point contact with friction, (vii) Soft finger* $(\eta_C > 0)$
Cylindrical	$\mathcal{K}_{\Phi_A} = 0,$	$\{\mathbf{C}(A_r, \boldsymbol{w}_\mathbf{a})\} \cdot \{\mathbf{R}(C, \boldsymbol{v})\} \cdot \{\mathbf{R}(B_r, \boldsymbol{w}_\mathbf{b})\} \cdot \{\mathbf{R}(B_R, \boldsymbol{u}_\mathbf{b})\}$ $(\eta_{B_r} = \eta_{B_R} = \eta_C = 0)$	Cylindrical-ball contact, Cylindrical-cylinder contact, Cylindrical-plane contact	Line-ball contact, Line-cylinder contact, Line-plane contact (or *(iii) Line contact without friction*), Frictional line-plane $(\eta_{B_r} > 0, \eta_C > 0)$ (or *(vi) Line-line contact without friction*), Fully-frictional line-plane

- All standard contact categories used in robotic manipulation, namely Salisbury's taxonomy along with line-line contact without friction, are obtained as special cases of this generalization
- New contact models, such as ball, tubular, planar translation, and frictional adaptive finger contacts, are defined and characterized from the proposed classification

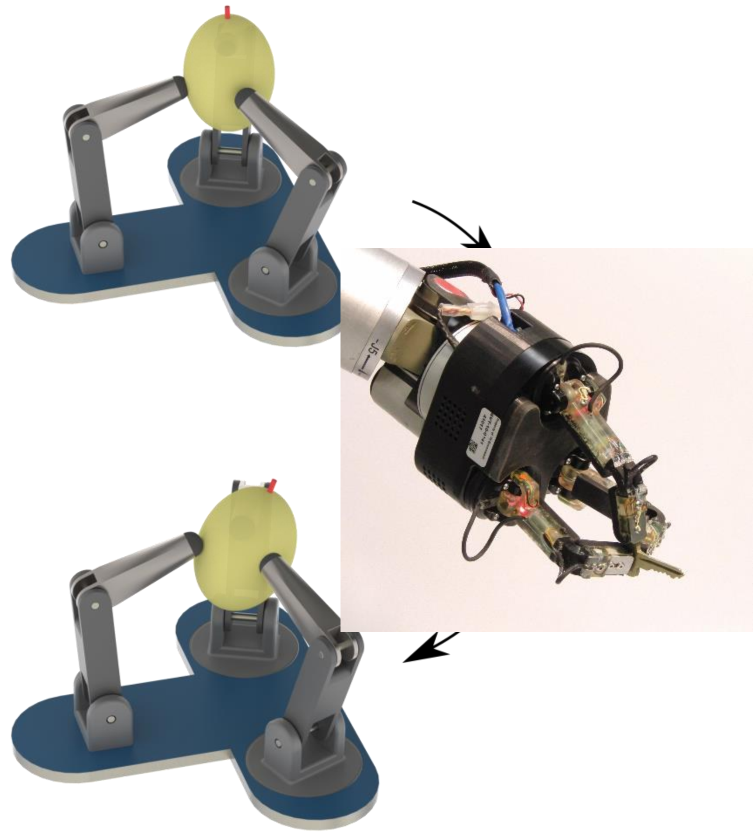
Our approach

A novel *intrinsic dexterity* approach based on flexible and adaptive mechanical components generating predictable behaviours of the hand-object system

Contact modelling

Manipulation analysis

Design of robot hands

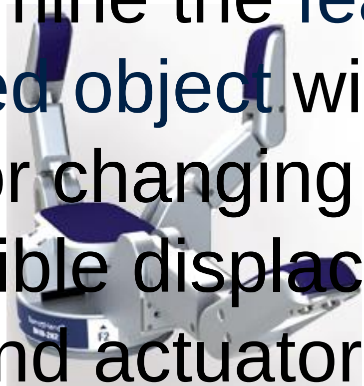


During precision manipulation, a grasped object is repositioned within the hand workspace without breaking or changing the assumed contact model between each fingertip and the object

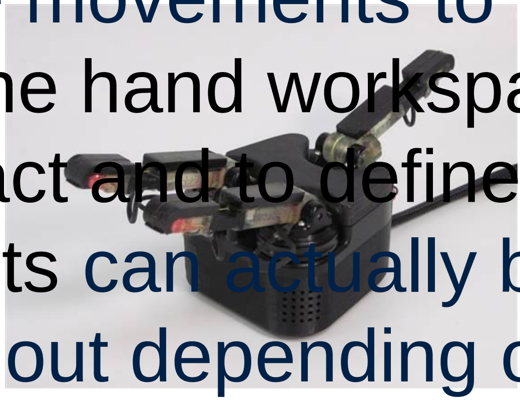
3-fingered hand with UR fingers and opposable RR thumb (3F-2UR1RR)

We want to determine the feasible movements to reposition <u>any</u> grasped object within the hand workspace without breaking or changing contact and to define which of these possible displacements can actually be controlled by the hand actuators without depending on external factors to the hand

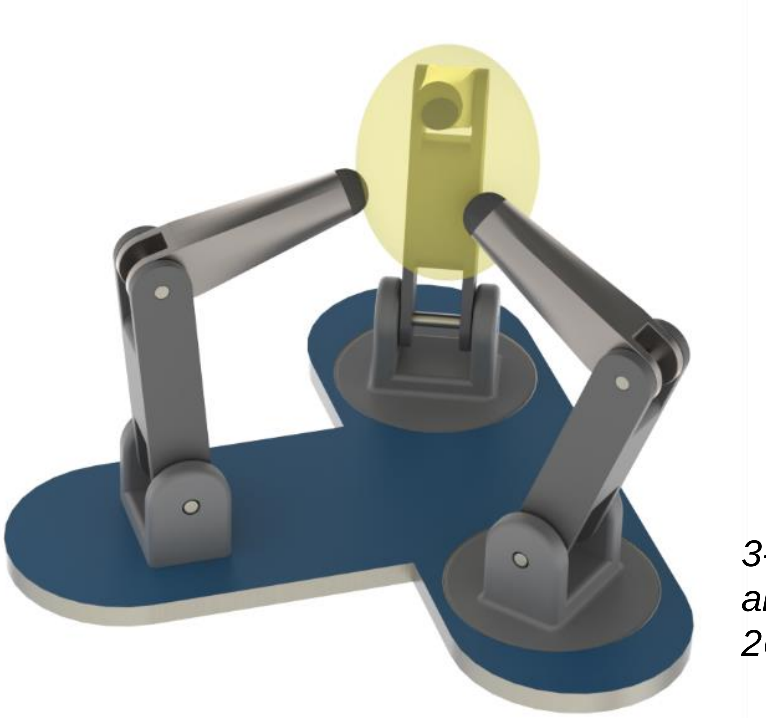
Schunk Hand



Barrett Hand



HY Hand

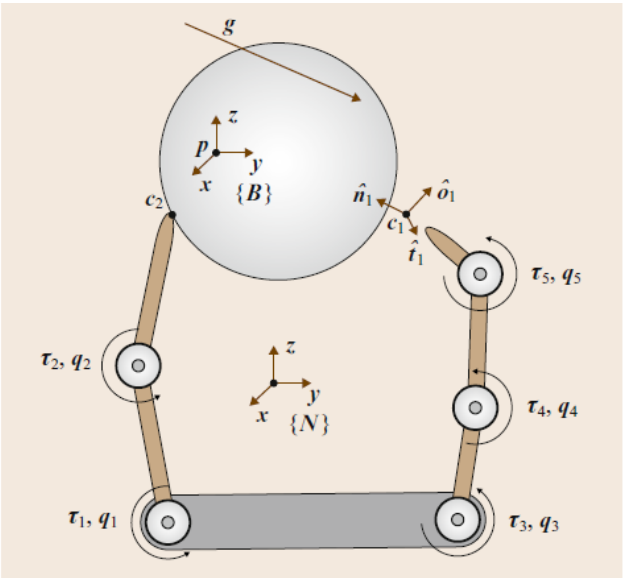


3-fingered hand with UR fingers and opposable RR thumb (3F-2UR1RR)

Precision (fingertip-based) manipulation analysis

N. Rojas and A.M. Dollar, "Gross Motion Analysis of Fingertip-Based Within-Hand Manipulation," IEEE Transactions on Robotics (T-RO), Vol. 32, No. 4, pp. 1009-1016, 2016

N. Rojas and A.M. Dollar, "Characterization of the Precision Manipulation Capabilities of Robot Hands via the Continuous Group of Displacements," Proceedings of the 2014 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Chicago, Illinois, USA, September 14-18, 2014



$$\begin{pmatrix} \boldsymbol{J} & -\boldsymbol{G}^\top \end{pmatrix} \begin{pmatrix} \dot{\boldsymbol{q}} \\ \boldsymbol{\nu} \end{pmatrix} = \boldsymbol{0}$$

$$\boldsymbol{G}^\top = \boldsymbol{H}\tilde{\boldsymbol{G}}^\top \in \mathbb{R}^{\ell \times 6}$$
$$\boldsymbol{J} = \boldsymbol{H}\tilde{\boldsymbol{J}} \in \mathbb{R}^{\ell \times n_q}$$

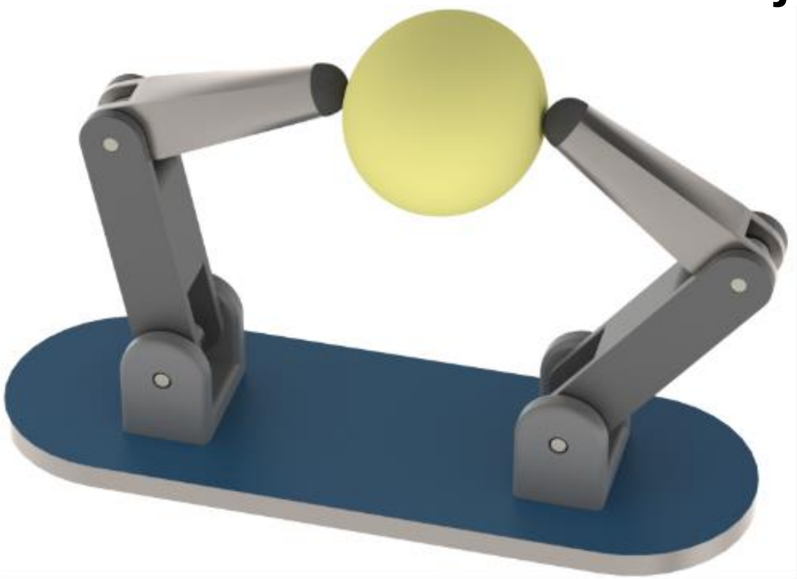
$$\boldsymbol{H}_i = \left[\begin{array}{cc} \boldsymbol{H}_{i\mathrm{F}} & \boldsymbol{0} \\ \hline \boldsymbol{0} & \boldsymbol{H}_{i\mathrm{M}} \end{array}\right]$$

Precision (fingertip-based) manipulation analysis

In general, an impossible task using standard techniques/models for grasping analysis

Precision manipulation analysis

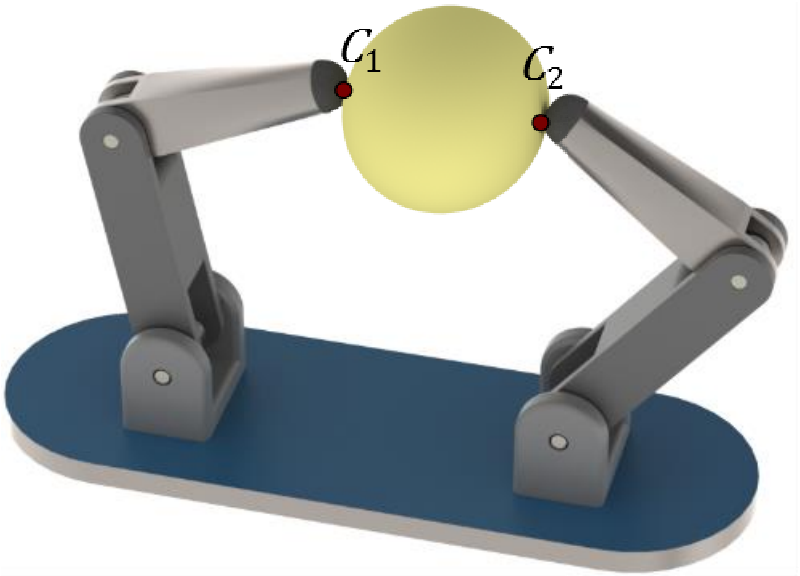
Our method is based on the kinematic analysis of the closed kinematic chain associated to the hand-object system



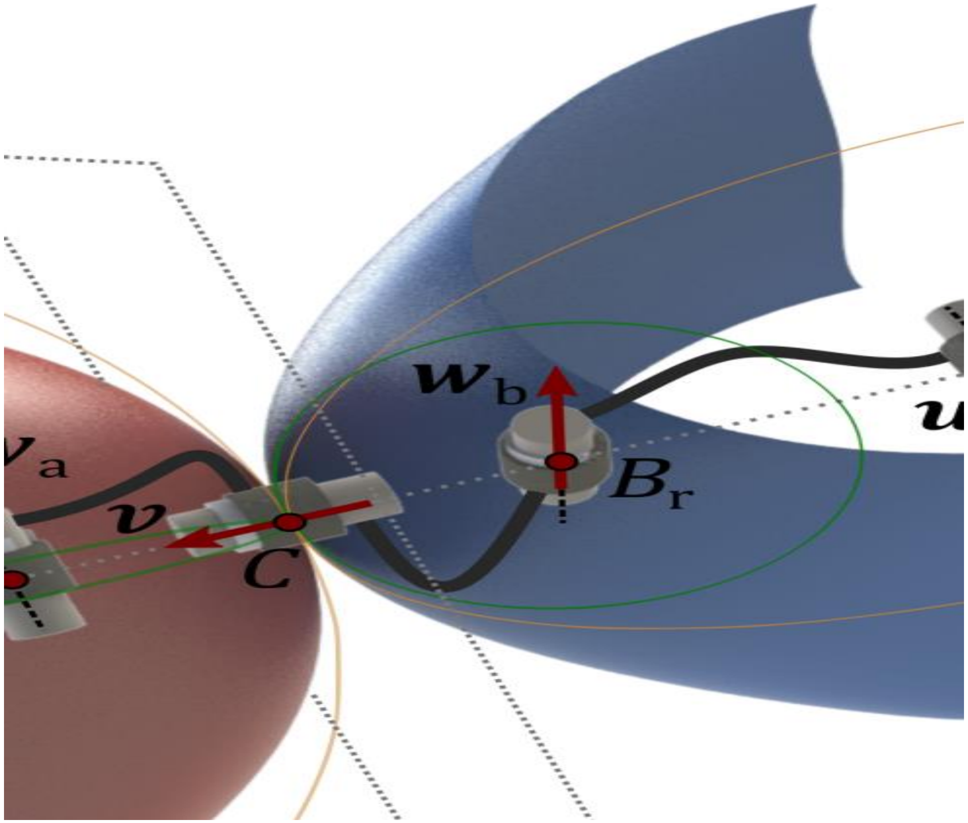
2-fingered hand with opposed RR fingers (2F-2RR)

Precision manipulation analysis

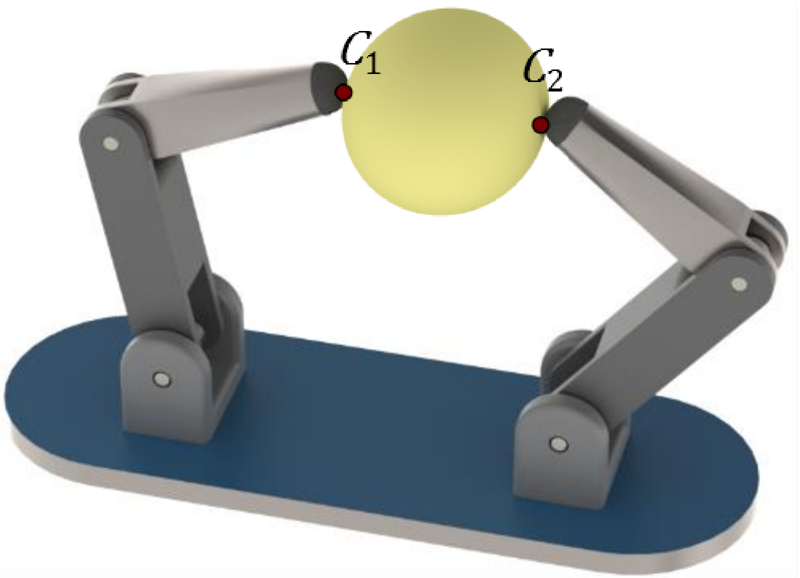
1. Model the contacts between the fingertips and the object using kinematic equivalents



2-fingered hand with opposed RR fingers (2F-2RR)



Precision manipulation analysis



2-fingered hand with opposed RR fingers (2F-2RR)

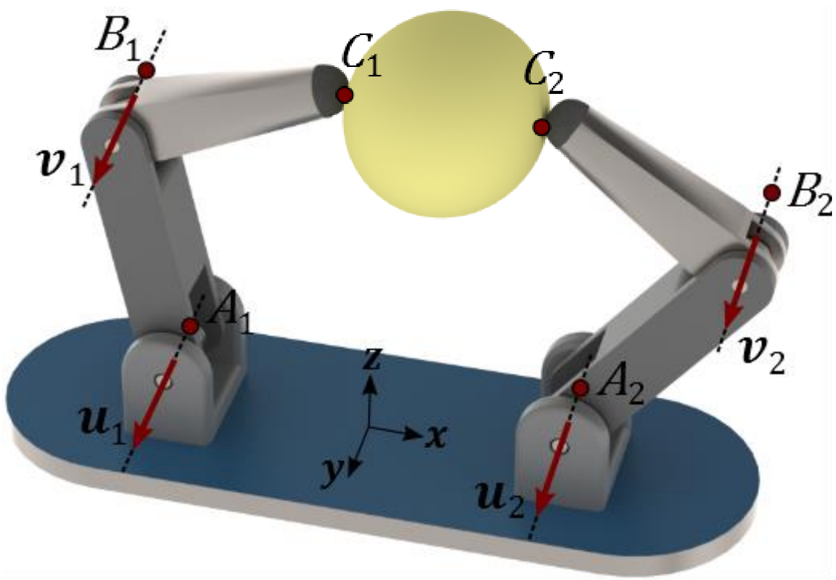
1. Model the contacts between the fingertips and the object using kinematic equivalents
2. Translate the hand-object system into a closed kinematic chain and determine its mobility

2F-2RR hand with point contact with friction

Closed kinematic chain: equivalent to a six-bar linkage with two RRS serial limbs

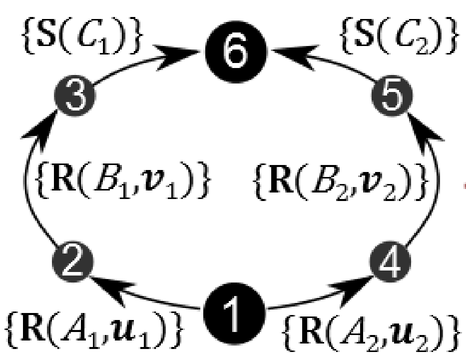
Mobility: 4

Precision manipulation analysis

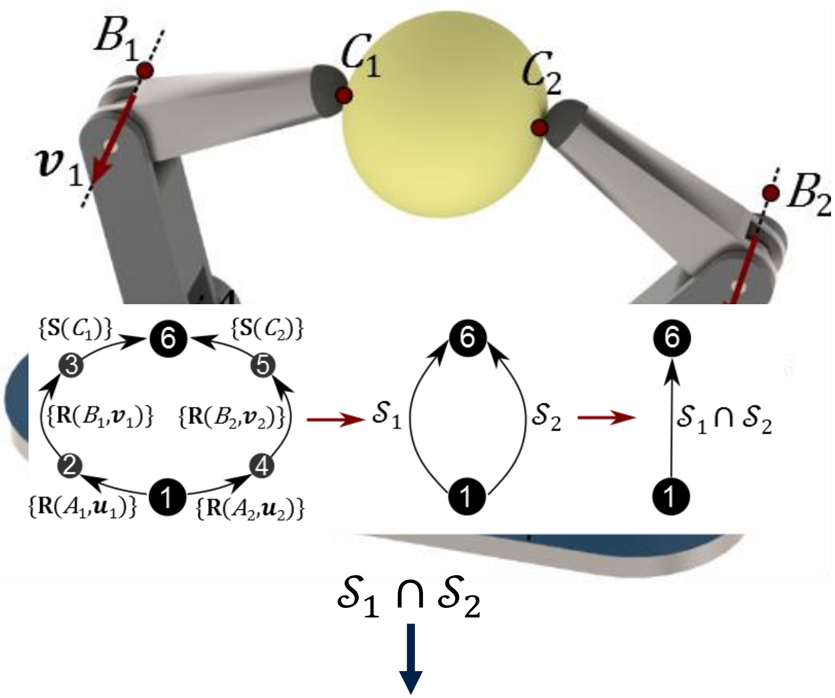


2-fingered hand with opposed RR fingers (2F-2RR)

1. Model the contacts between the fingertips and the object using kinematic equivalents
2. Translate the hand-object system into a closed kinematic chain and determine its mobility
3. Construct the corresponding graph of kinematic constraints



Precision manipulation analysis



$$\{\mathbf{G}(\boldsymbol{y})\} \cdot \{\mathbf{R}(C_1, \widehat{\boldsymbol{c}_1\boldsymbol{c}_2})\}$$

1. Model the contacts between the fingertips and the object using kinematic equivalents
2. Translate the hand-object system into a closed kinematic chain and determine its mobility
3. Construct the corresponding graph of kinematic constraints
4. Reduce the resulting graph of kinematic constraints using Hervé’s group-theoretic approach

Precision manipulation analysis

Definition of the general displacement characteristics (*i.e. composition of the displacement manifold*) of any grasped object relative to the palm

1. Model the contacts between the fingertips and the object using kinematic equivalents
2. Translate the hand-object system into a closed kinematic chain and determine its mobility
3. Construct the corresponding graph of kinematic constraints
4. Reduce the resulting graph of kinematic constraints using Hervé's group-theoretic approach

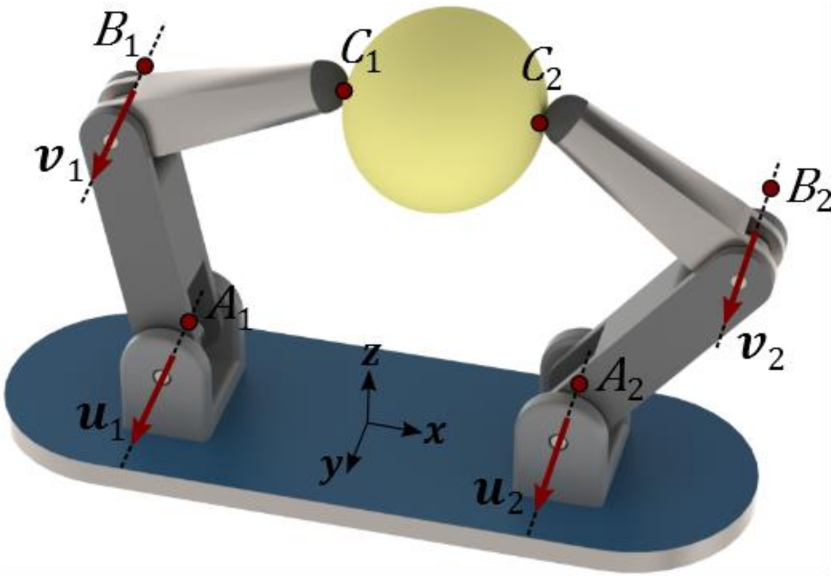
Precision manipulation analysis

Determination of the displacements that can actually be controlled by the hand actuators without depending on external factors to the hand

Lock actuators and repeat 1-4

1. Model the contacts between the fingertips and the object using kinematic equivalents
2. Translate the hand-object system into a closed kinematic chain and determine its mobility
3. Construct the corresponding graph of kinematic constraints
4. Reduce the resulting graph of kinematic constraints using Hervé’s group-theoretic approach

Precision manipulation analysis



$\mathcal{S}_1 \cap \mathcal{S}_2$

$$\{\mathbf{G}(\boldsymbol{y})\} \cdot \{\mathbf{R}(C_1, \widehat{\boldsymbol{c}_1\boldsymbol{c}_2})\}$$

1. Model the contacts between the fingertips and the object using kinematic equivalents
2. Translate the hand-object system into a closed kinematic chain and determine its mobility
3. Construct the corresponding graph of kinematic constraints
4. Reduce the resulting graph of kinematic constraints using Hervé’s group-theoretic approach

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A novel *intrinsic dexterity* approach based on flexible and adaptive mechanical components generating predictable behaviours of the hand-object system

Contact modelling

Manipulation analysis

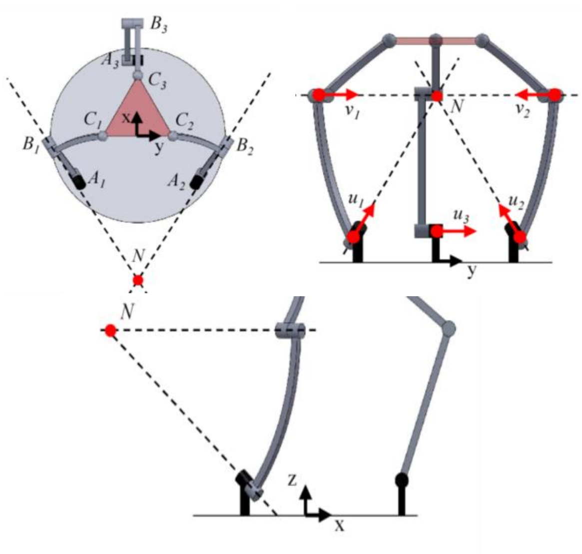
Design of robot hands

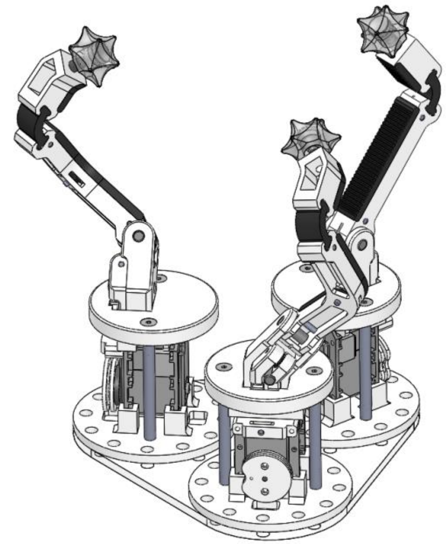
Design of robot hands

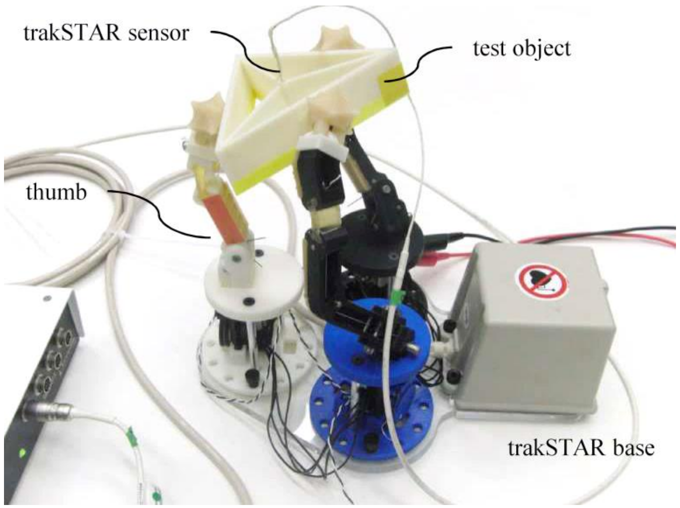
- Spherical Hands
- GR2 gripper
- Coalesced topology

Design of robot hands

Spherical Hands

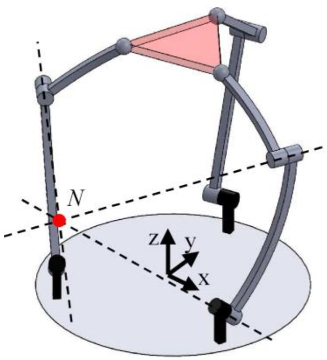


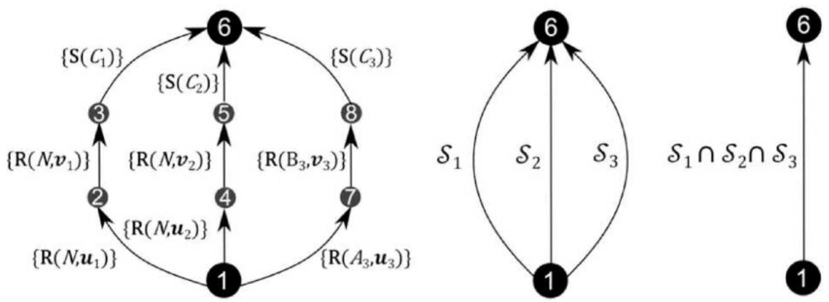




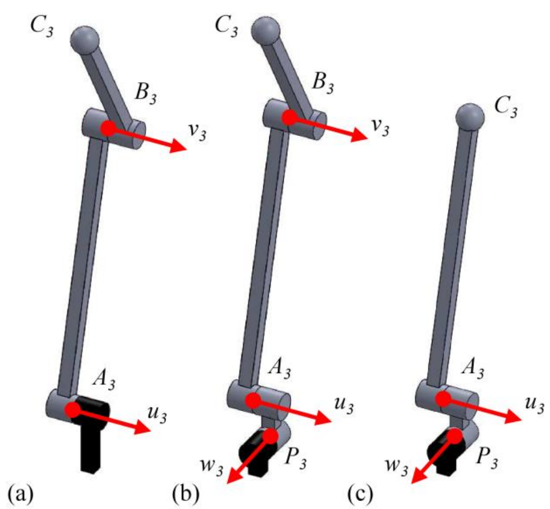
Novel, underactuated 3-fingered hand topologies with two curved fingers where the instantaneous screw axes, describing the displacement of the grasped object, always intersect at the same point relative to the palm

Design of robot hands
Spherical Hands





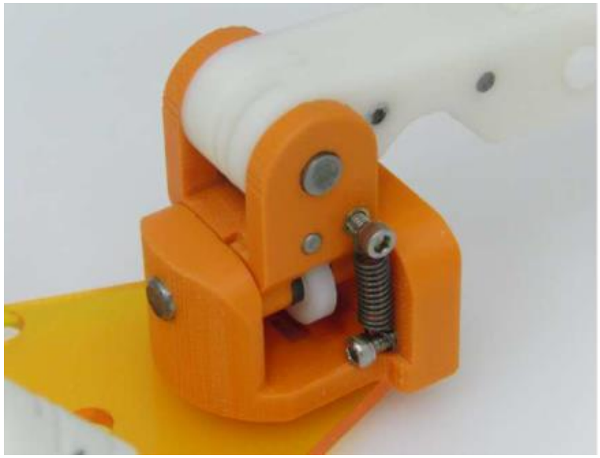
$$
\begin{aligned}
\mathcal{P}_3 &= \mathcal{P}_1 \cap \mathcal{P}_2 \\
&= \{\mathbf{S}(N)\} \cdot \{\mathbf{R}(C_1, \widehat{\boldsymbol{c}_1\boldsymbol{c}_2})\} \;\cap\; \{\mathbf{S}(N)\} \cdot \{\mathbf{R}(C_2, \boldsymbol{j}_2)\} \\
&= \{\mathbf{S}(N)\} \cdot (\{\mathbf{R}(C_1, \widehat{\boldsymbol{c}_1\boldsymbol{c}_2})\} \cap \{\mathbf{R}(C_2, \boldsymbol{j}_2)\}) \\
&= \{\mathbf{S}(N)\}
\end{aligned}
$$

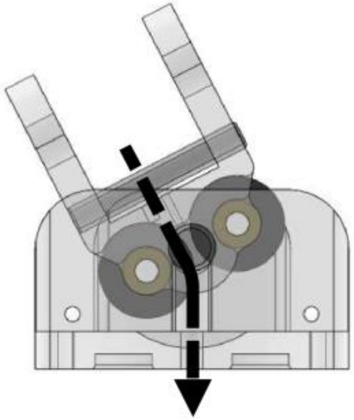


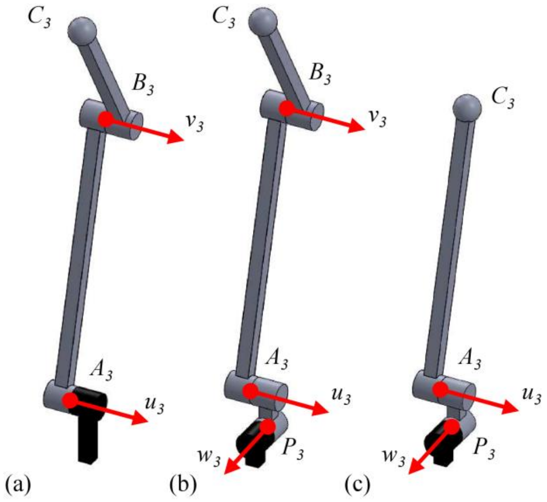
Three thumb designs: *(a) 2-link thumb with static base, (b) 2-link thumb with pivot base, (c) 1-link thumb with pivot base*

Design of robot hands

Spherical Hands

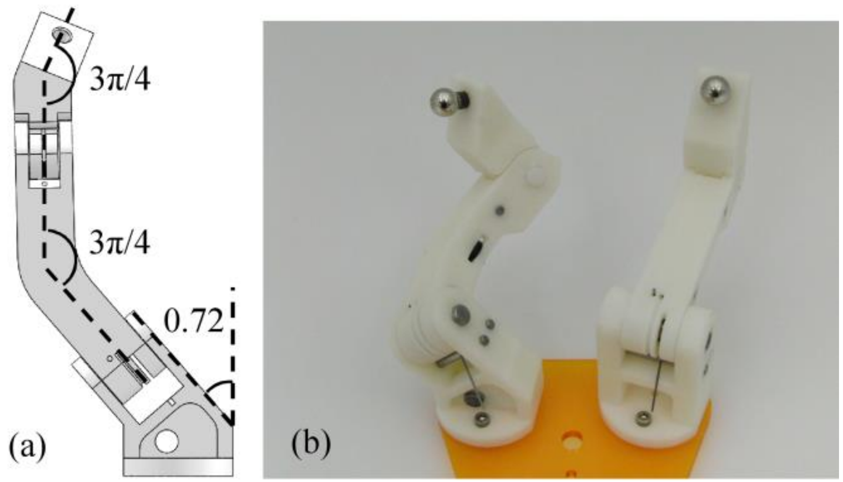


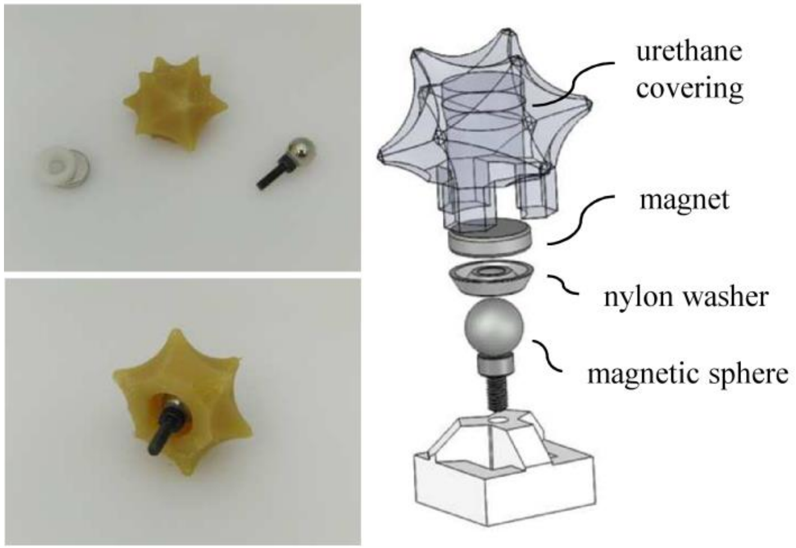




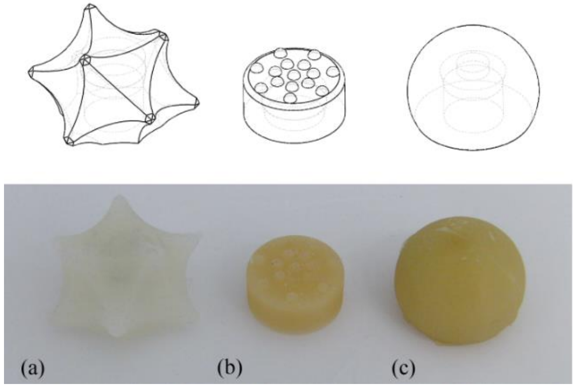
The passive, pivoting degree of freedom is implemented such that it is not actuated by the main drive tendon

Design of robot hands
Spherical Hands



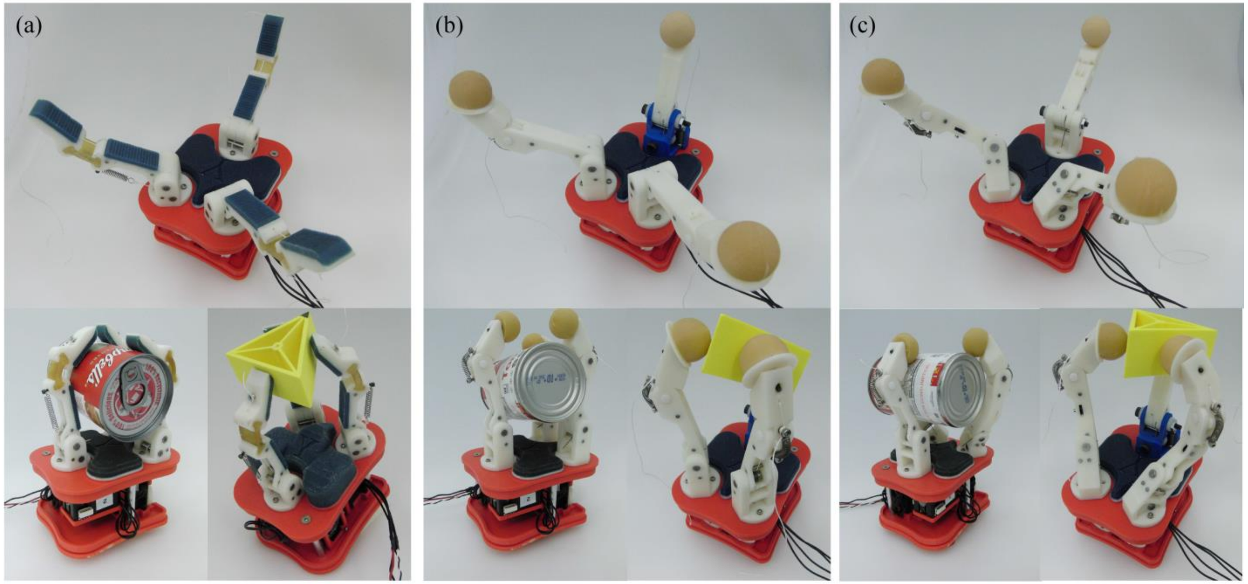


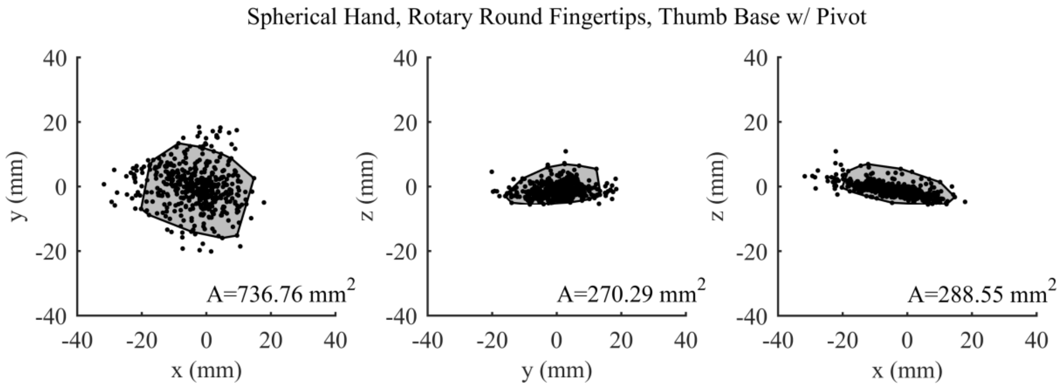
Multiple fingertip designs were evaluated, constructed of a monolithic, cast urethane shell

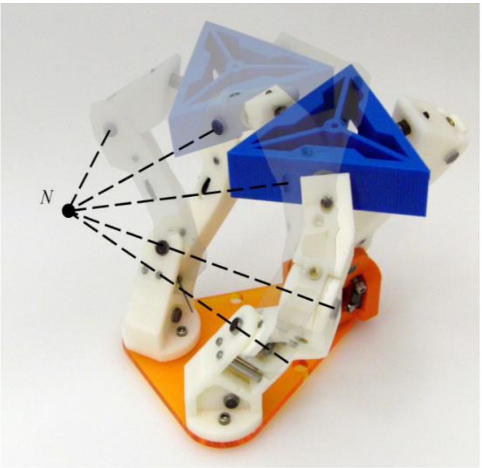


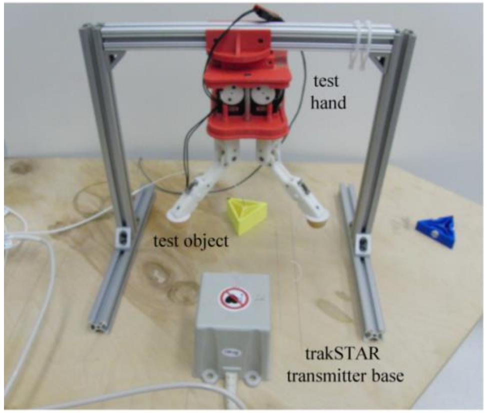
Design of robot hands

Spherical Hands





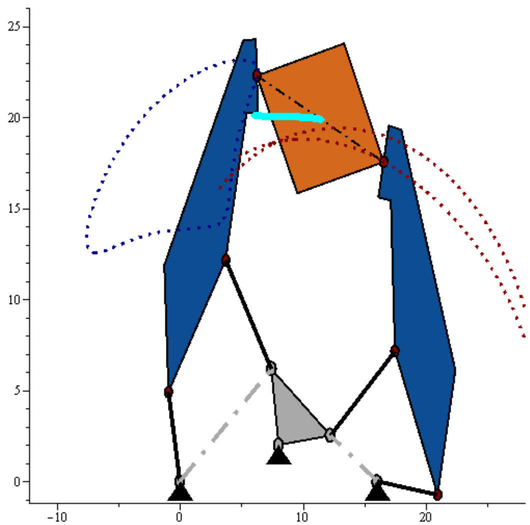


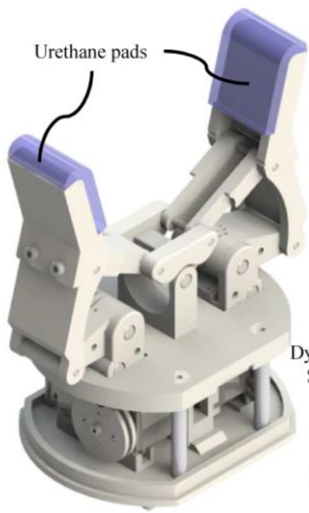


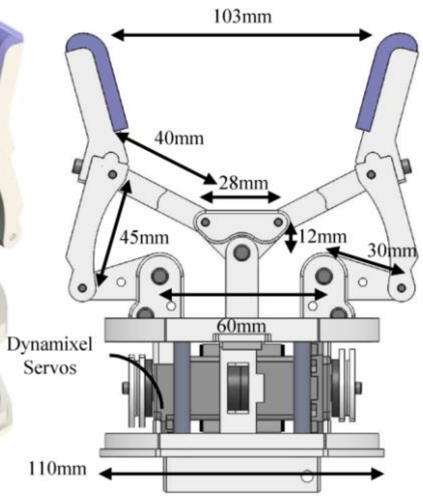
R.R. Ma, N. Rojas, and A.M. Dollar, "Spherical Hands: Toward Underactuated, In-Hand Manipulation Invariant to Object Size and Grasp Location," *ASME Journal of Mechanisms and Robotics*, Vol. 8, No. 6, 061021 (12 pages), 2016

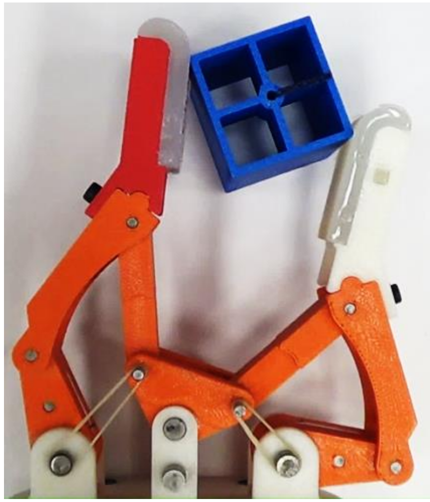
R.R. Ma, N. Rojas, and A.M. Dollar, "Towards Predictable Precision Manipulation of Unknown Objects with Underactuated Fingers," *Proceedings of the 3rd IEEE/IFToMM International Conference on Reconfigurable Mechanisms and Robots (ReMAR)*, Beijing, China, July 20-22, 2015. ***Winner, Best Student Paper Award***

Design of robot hands
GR2 gripper









An underactuated hand for
open-loop in-hand planar manipulation

Design of robot hands
GR2 gripper

The *grasp-reposition-reorient* (GR2) gripper is a two-fingered gripper topology that enables an enhanced predefined in-hand manipulation primitive controlled without knowing the size, shape, or other particularities of the grasped object

Design of robot hands

GR2 gripper

Why?

While single-degree-of-freedom two-finger robot grippers are prevalent in industrial and research settings…

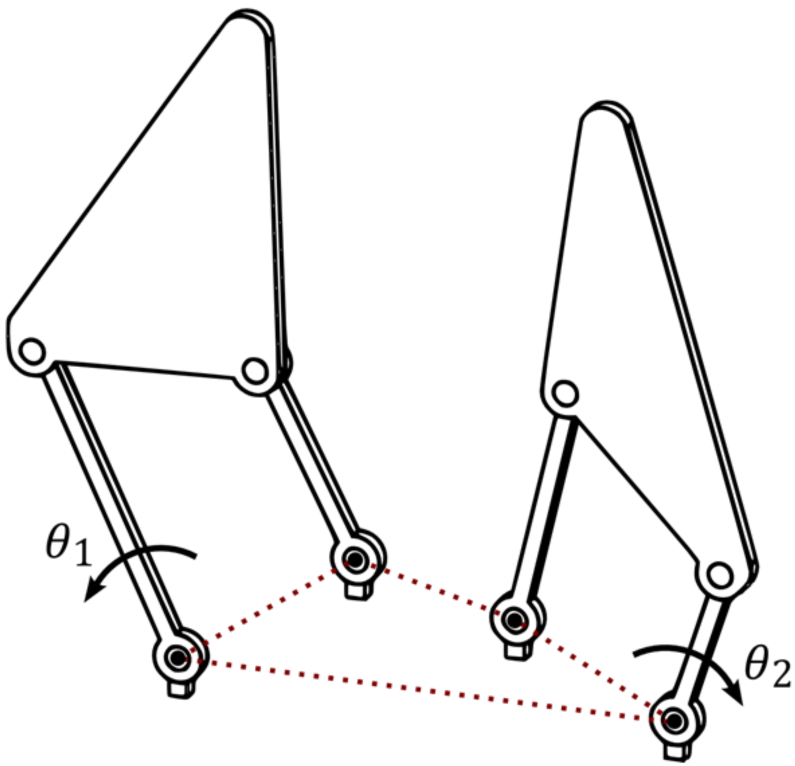
they can be limited outside of pick-and-place operations

The alignment of parts before assembly processes (e.g. a peg-in-hole alignment task) exemplifies the type of limitations

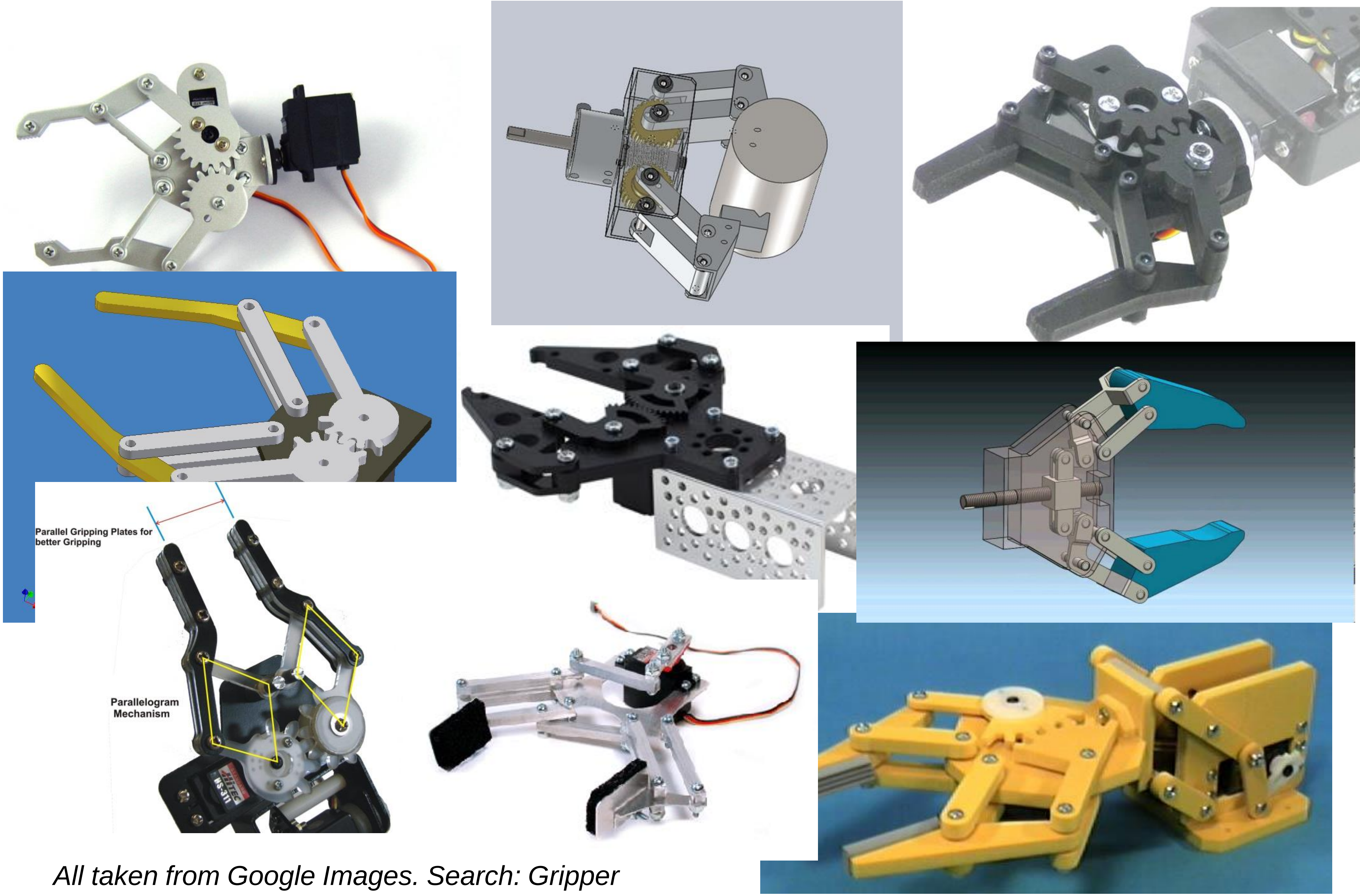
- *Mechanical simplicity*
- *Reliability*
- *Low cost*
- *Force capabilities*

Design of robot hands

GR2 gripper



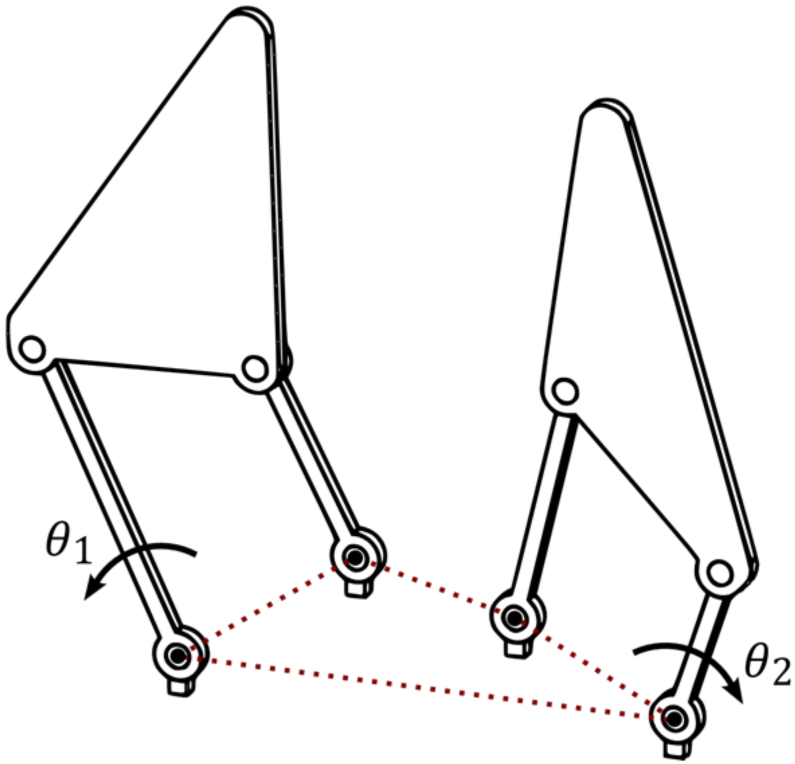
A generic instance of a traditional two-finger robot gripper with four-bar-linkage fingers



All taken from Google Images. Search: Gripper

Design of robot hands

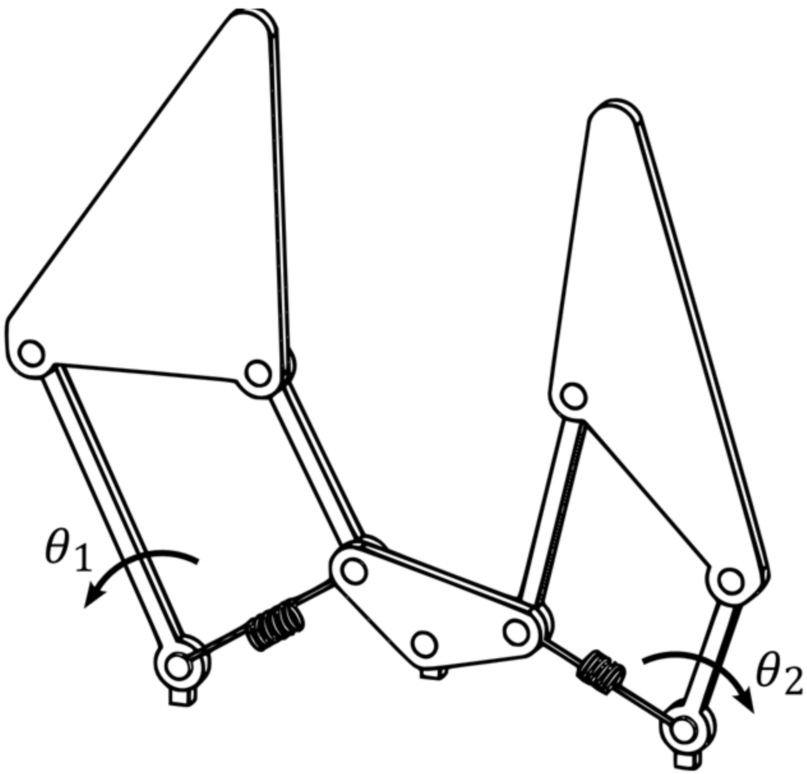
GR2 gripper



This mechanism has been historically employed solely for grasping operations, without considering any feasible capacity of dexterity

Design of robot hands

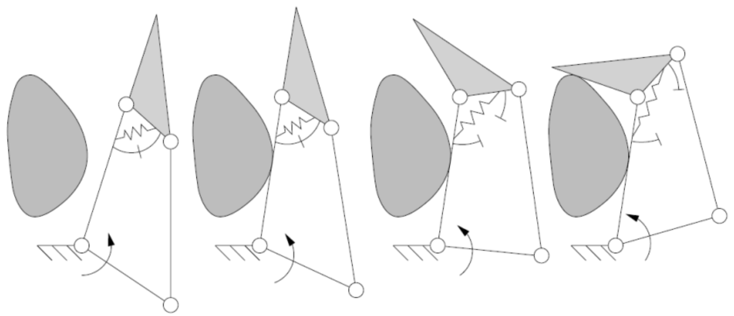
GR2 gripper



Generic instance of the GR2 gripper concept

N. Rojas, R.R. Ma, and A.M. Dollar, "The GR2 Gripper: An Underactuated Hand for Open-Loop In-Hand Planar Manipulation," *IEEE Transactions on Robotics*, Vol. 32, No. 3, pp. 763 - 770, 2016

Design of robot hands
GR2 gripper



(L. Birglen, T. Laliberte, and C. Gosselin, STAR 2008)

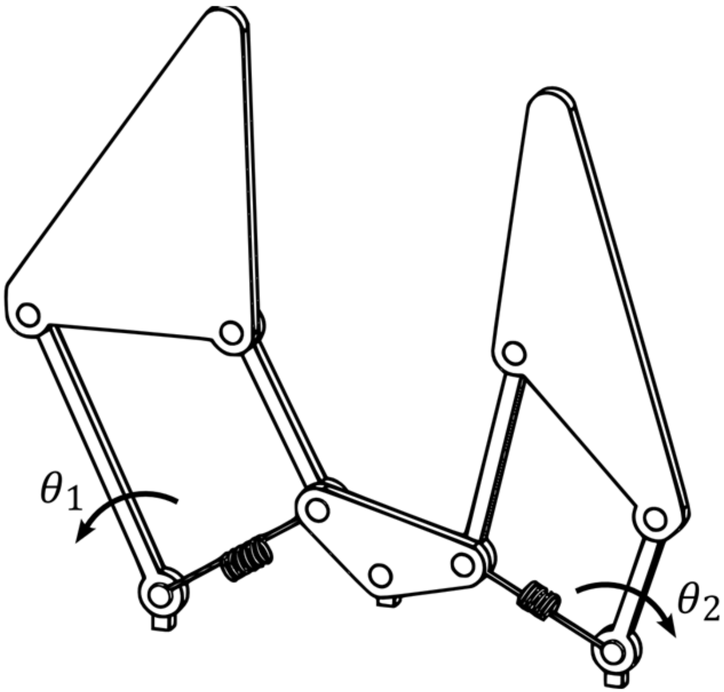
Robotiq 2-Finger 85

Previously proposed designs independently incorporate elastic elements in each finger for performing adaptive grasping operations

Design of robot hands

GR2 gripper

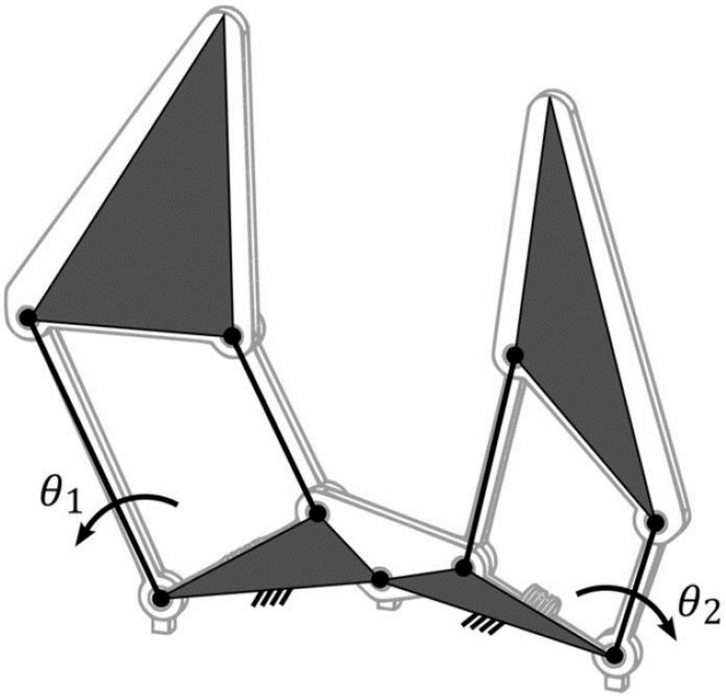
In a GR2 gripper, the elastic elements of the fingers are coupled through a pivot joint in order to improve the in-hand manipulation behavior by passively changing the configuration of the palm after the initial grasp is achieved



Design of robot hands

GR2 gripper

Grasping and in-hand manipulation



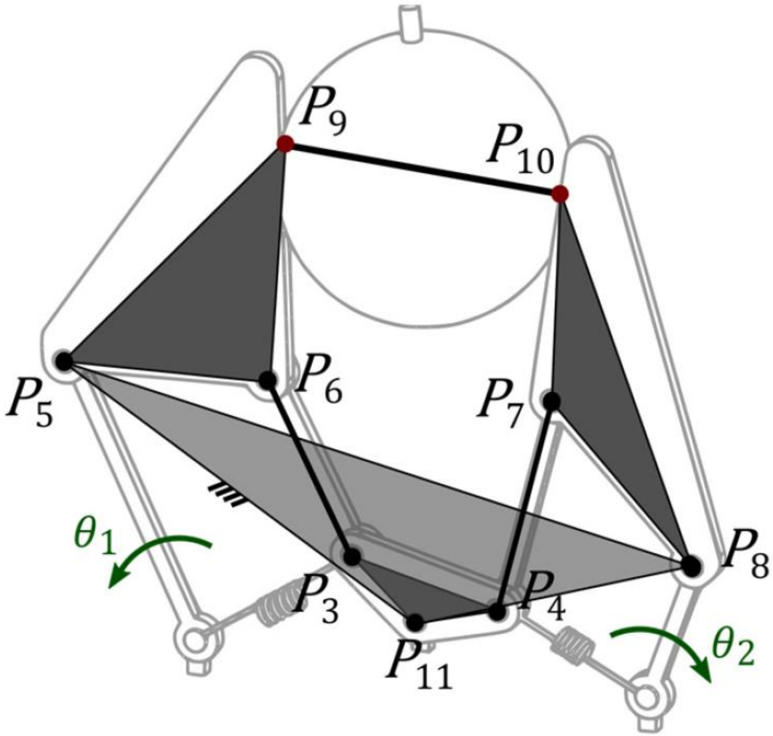
In the approaching phase to grasp an object, a GR2 gripper behaves as a traditional two-finger gripper

Design of robot hands

GR2 gripper

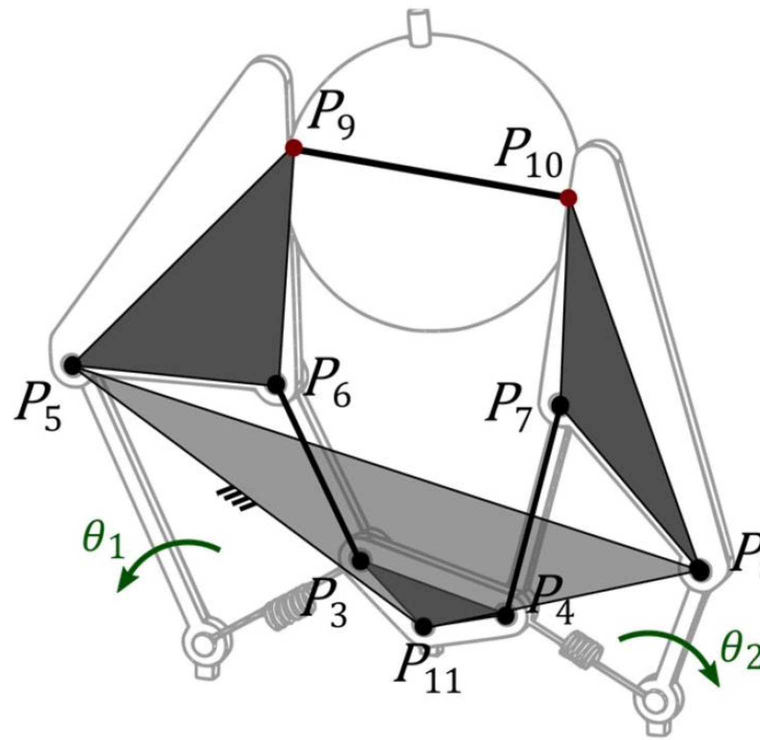
Grasping and in-hand manipulation

Once the object is grasped, the input angles are fixed and the hand-object system constitutes a closed mechanism with a truss



Design of robot hands
GR2 gripper
Grasping and in-hand manipulation

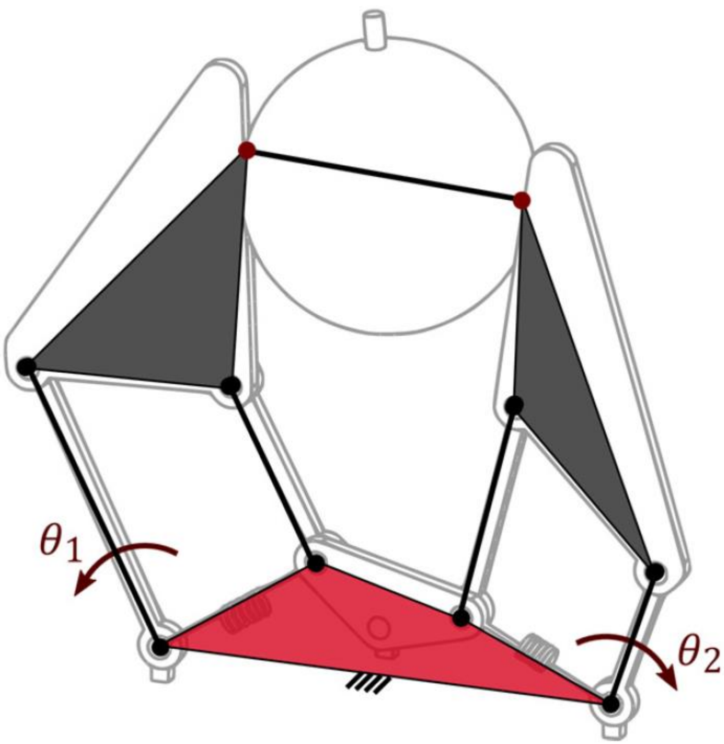
The rigidness of the grasp is geometrically guaranteed regardless of the condition of the tension springs



Design of robot hands

GR2 gripper

Grasping and in-hand manipulation



During in-hand manipulation tasks, the closed kinematic chain of the hand-object system corresponds to a reconfigurable linkage with a quaternary link that passively modifies its geometry

Example 1

Object: ***Square (Corner Contact)***
Width: ***35mm (49.5mm between corners)***

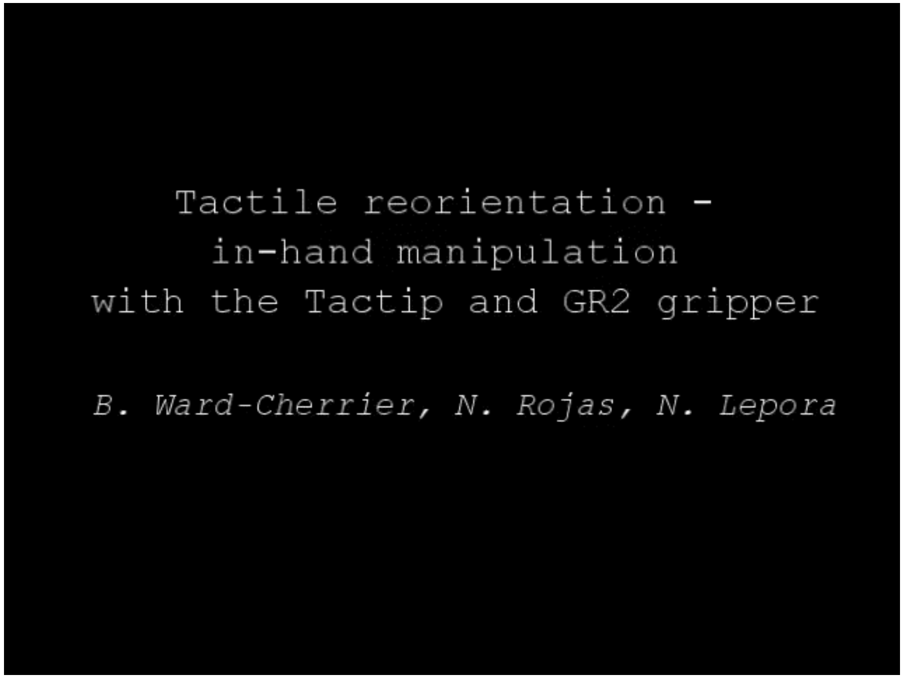
Elastic elements of the fingers are coupled through a pivot joint to improve the in-hand manipulation behavior by passively changing the configuration of the palm

N. Rojas, R.R. Ma, and A.M. Dollar, "The GR2 Gripper: An Underactuated Hand for Open-Loop In-Hand Planar Manipulation," *IEEE Transactions on Robotics*, Vol. 32, No. 3, pp. 763 - 770, 2016

Design of robot hands

GR2 gripper

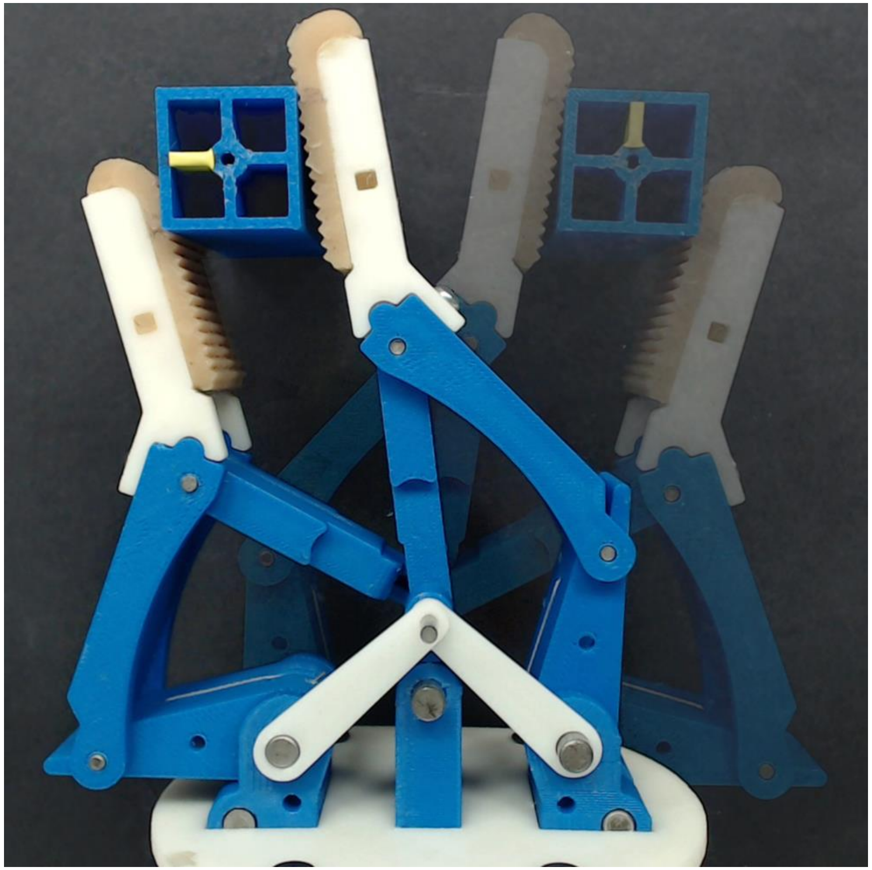
Model-free in-hand manipulation



B. Ward-Cherrier, N. Rojas, and N.F. Lepora, “Model-Free Precise In-Hand Manipulation with a 3D-Printed Tactile Gripper,” IEEE Robotics and Automation Letters (RA-L), Vol. 2, No. 4, pp. 2056-2063, 2017
(2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Vancouver, BC, Canada, September 24-28, 2017)

Design of robot hands

Coalesced topology



Able to reorient objects in excess of $\pi/2$ rad while maintaining a stable grasp, without using high-fidelity contact sensors, active/sliding finger surfaces, or *a priori* workspace exploration.

W.G. Bircher, A.M. Dollar, and N. Rojas, "A Two-Fingered Robot Gripper with Large Object Reorientation Range," Proceedings of the 2017 IEEE International Conference on Robotics and Automation (ICRA), Singapore, May 29 - June 3, 2017. ***Finalist of the Best Robotic Manipulation Paper Award***

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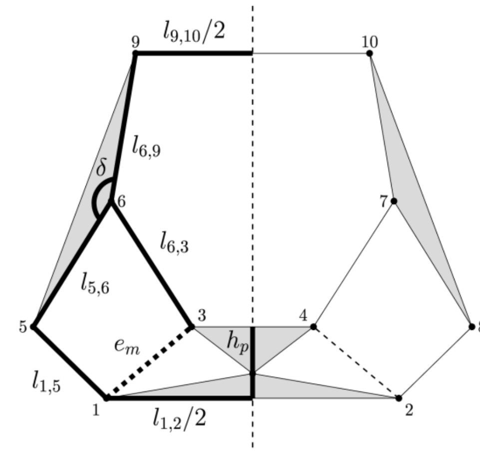

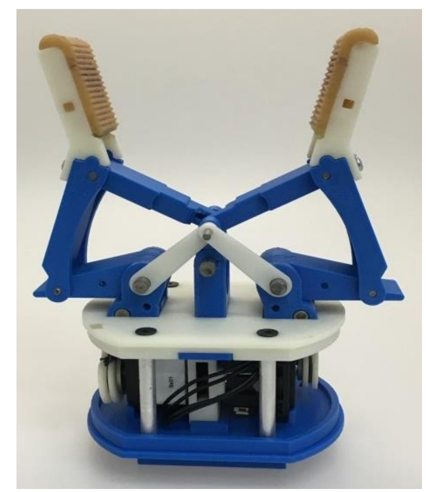

Two kinematic parameter search optimizations connected in cascade. Gripper is a new topology

W.G. Bircher, A.M. Dollar, and N. Rojas, “A Two-Fingered Robot Gripper with Large Object Reorientation Range,” Proceedings of the 2017 IEEE International Conference on Robotics and Automation (ICRA), Singapore, May 29 - June 3, 2017. ***Finalist of the Best Robotic Manipulation Paper Award***

Thanks!

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