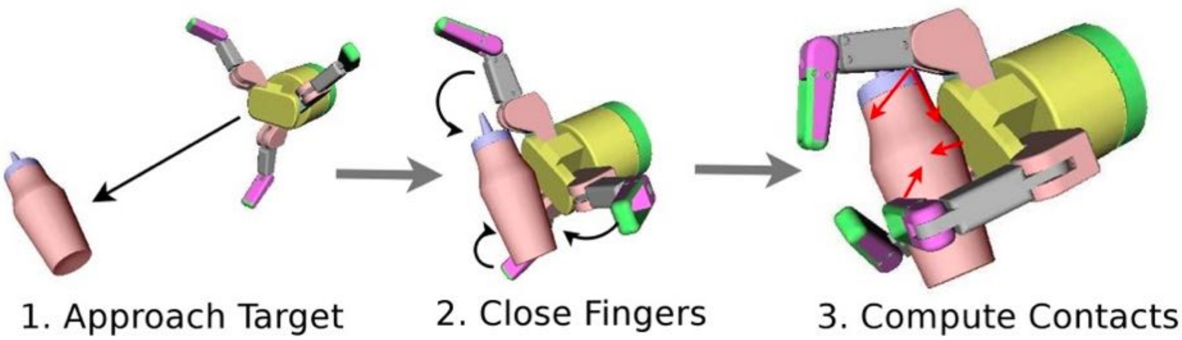
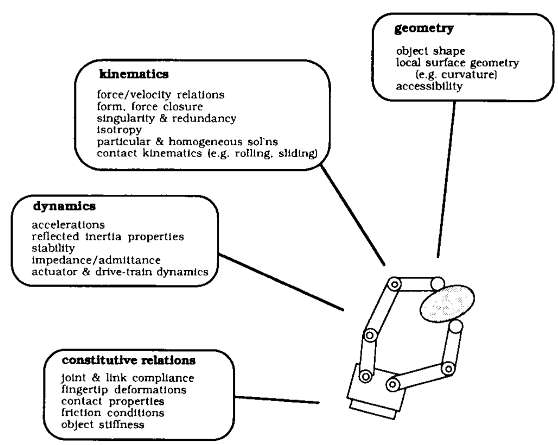


Hands & Grasping

Henrik I Christensen

Outline

- Mechanisms for hand design
- Example hand designs
- Issues in grasping
- Control and stability
- Grasp strategies
- Grasp evaluation
- Summary



Source: Cutkosky, TRO 1989

- Material from Handbook of Robotics, Siciliano & Khatib, Springer; GraspIt, P. Allen et al, Columbia; Grasp modeling, J. Trinkle, RPI, ...

Effector considerations

- What is the objective of the hand/end-effector?
  - Solving the problem?
  - Make it anthropomorphic?
- Industrial end-effectors
  - Often as expensive as the manipulator or more
  - There is an industry that designs end-effectors
  - Actuation can be electric or pneumatic
- Anthropomorphic
  - Easy of use in a human environment (maybe less relevant in industry)

Dexterity of a robot hand

- Prehension
  - The ability to grasp and hold objects of varying size and shape
- Apprehension
  - The ability to explore and comprehend objects through active touch

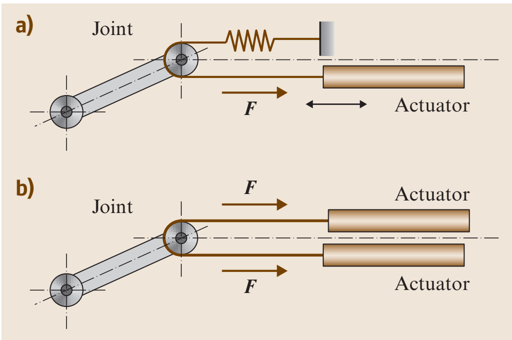
- Dexterity is often characterized by the variability in the objects handled
- Dexterity can also be considered through
  - Objects that can be grasped
  - The degree of internal manipulation possible

(c) Henrik I Christensen

Design of hands

- Actuation?
  - Direct drive
  - Link host actuation
- Actuation architecture
  - Consider a hand with N joints, and M actuators
  - M < N, Some joints are passive, compliant or underactuated
  - M=N, Each joint has its own actuator
  - M>N, Some joints have more than one actuator

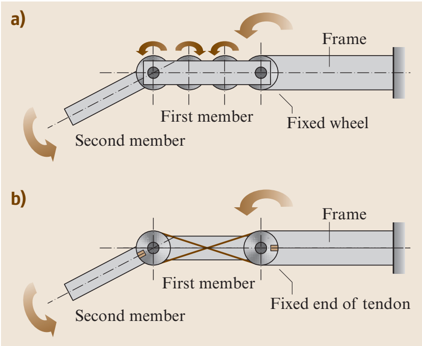
Single actuator - Agonistic / Antagonistic



Source: Handbook of Robotics, 2010

- Enable variable stiffness
- Increased flexibility in design
- Added complexity
- Motors must be back-drivable
- Space considerations

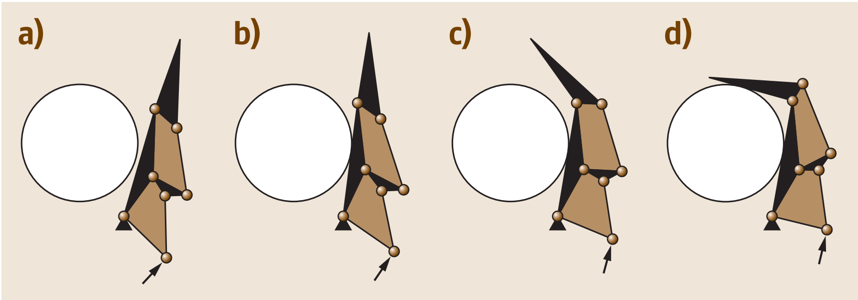
N+1 Actuation Network



Source: Handbook of Robotics, 2010

- Coupled actuator system
- Simplified design
- Failure on one part will result in general failure

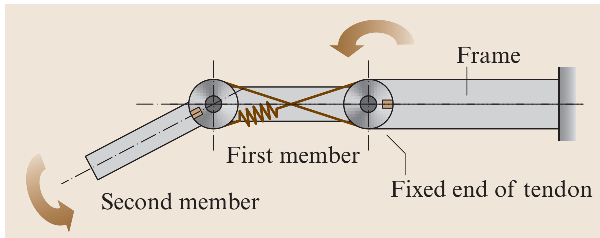
Grasping in under-actuated systems



Source: Handbook of Robotics, 2010

- Sometimes passive compliance simplifies grasping
- An example where use of a palm is valuable

Flexible coupled joints



Source: Handbook of Robotics, 2010

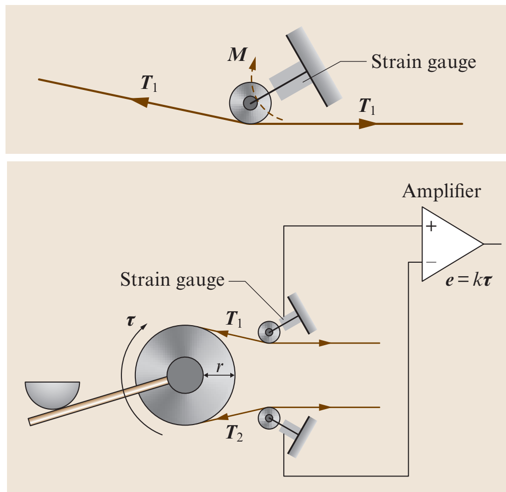
- In some cases it is convenient to have simple closure
- Using spring coupled links to achieve variable compliance

Actuation

- For small hands the typical is to use electrical actuators
  - Great progress on torque/power/size compromise
- Larger scale industrial actuators often rely on pneumatic
  - Airflow can be considerable
  - Noisy in many cases
- Tremendous progress on design of systems

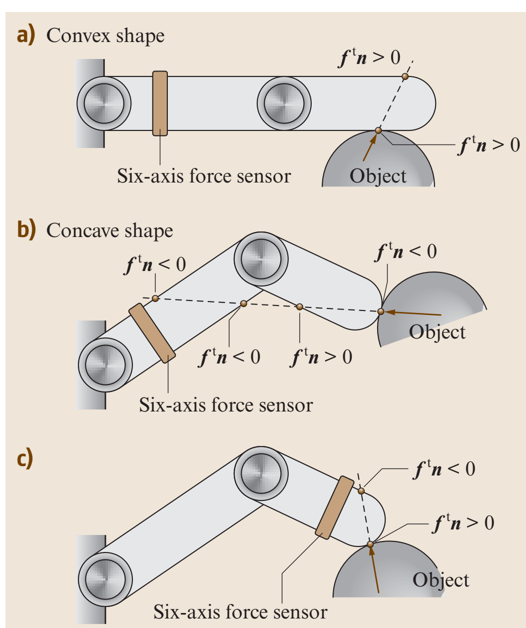
Sensing of tendon force?

- A number of typical designs
- Avoid cutting the tendon



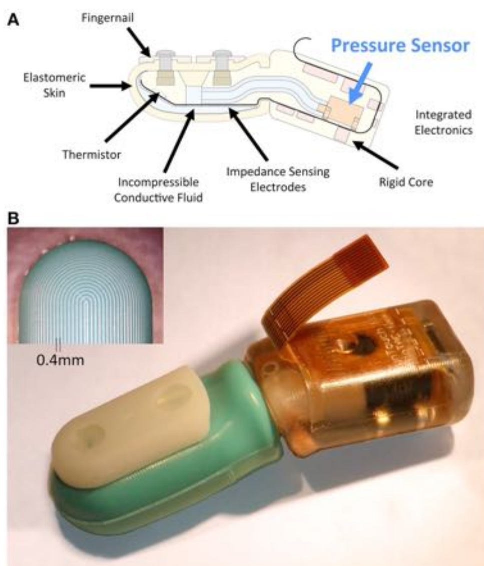
Source: Handbook of Robotics, 2010

Force sensing



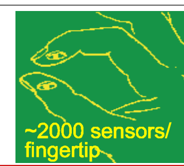
Source: Handbook of Robotics, 2010

Haptic sensing on finger tips

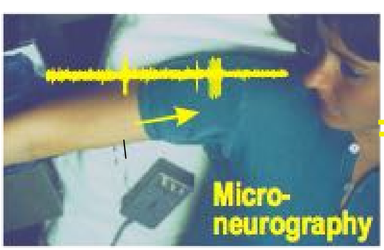


- Highly sensitive fingertip sensor
- BioTac Sensor from SynTouch
- Recently reported to have performance on par with humans for surface discrimination
- [Fishel and Loeb, Frontiers in Neurorobotics, June 2012]

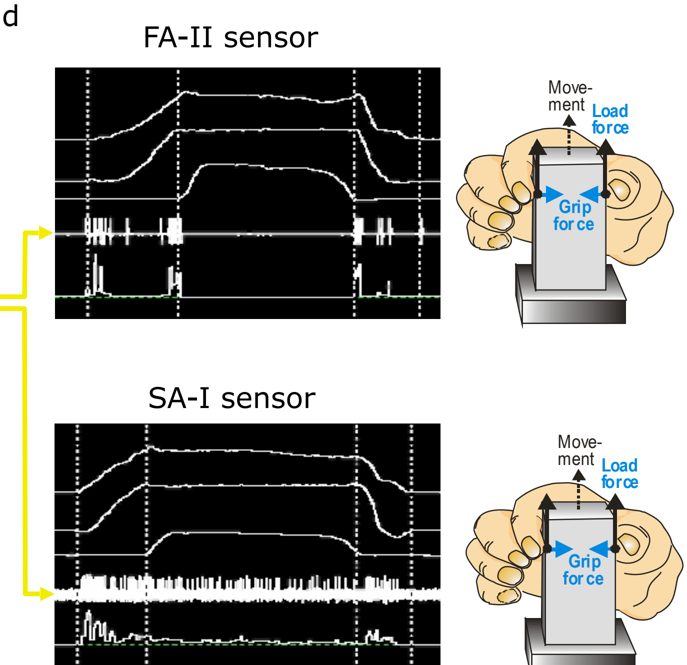
How do you explore human sensing



- Nerve signals from the hand can be measured during manipulation

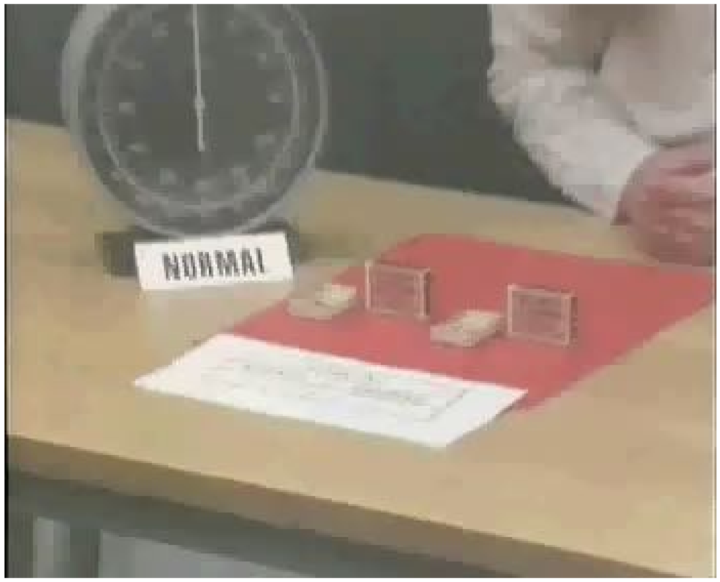


- Different sensors measure different mechanical characteristics



Source: R. Johanson

Normal - Manipulation

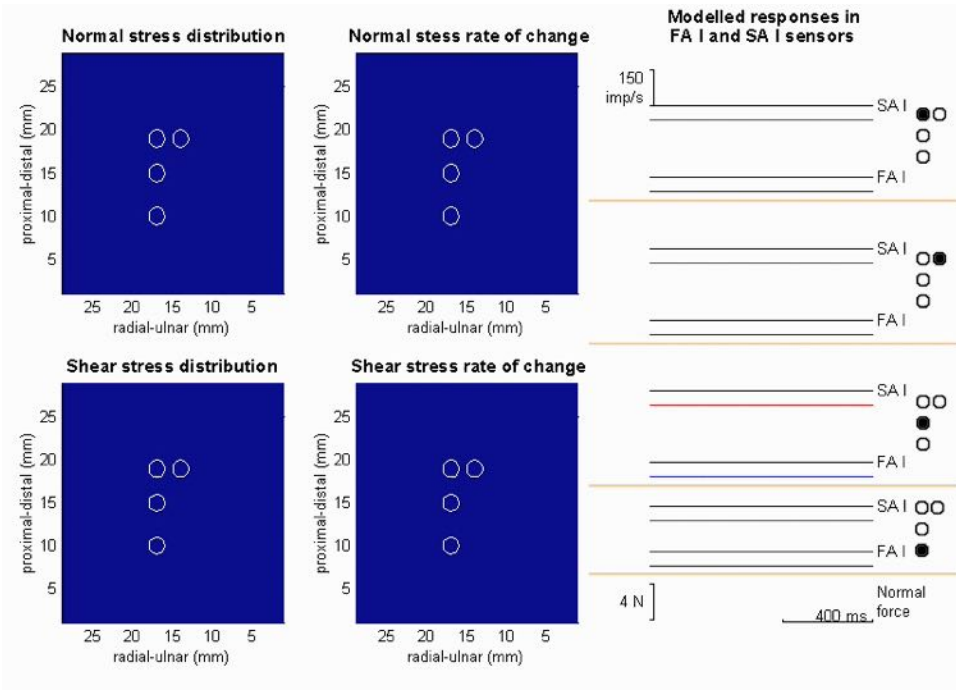


Source: R. Johanson

Manipulation w. anesthetized

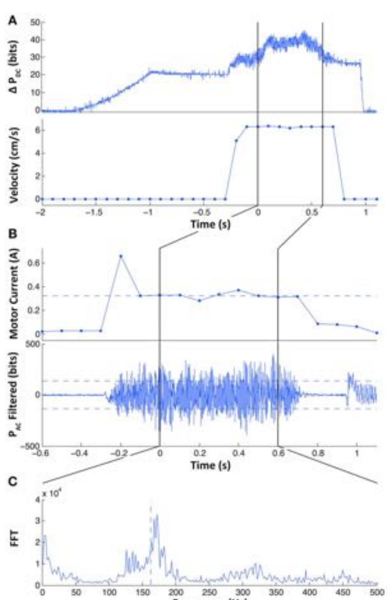
Source: R. Johanson

Nerve signals



Christensen

Example of exploration



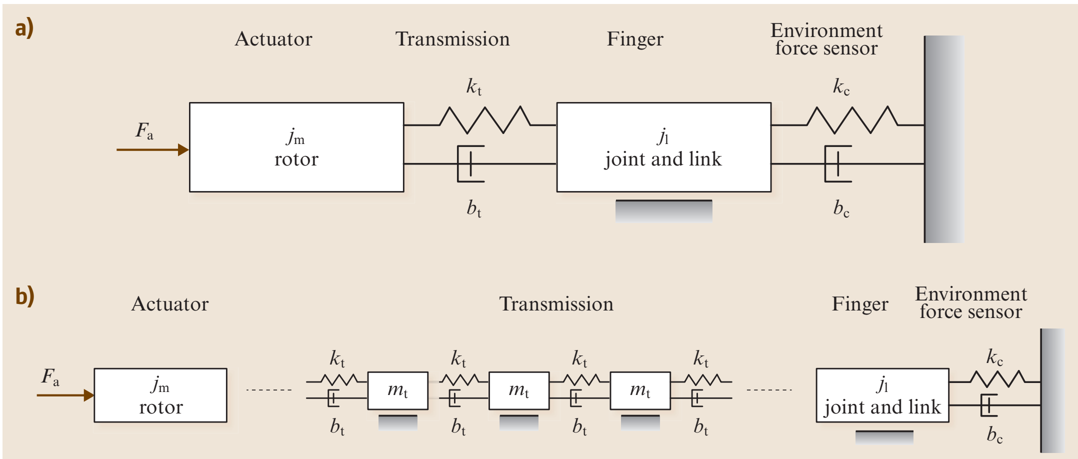
Source: Fishel & Loeb, FoN, June 2012

- Consideration of normal force
- Variation as a function of velocity
- Normalized force profile
- Analysis of the frequency spectrum
- Consideration of roughness, texture, ...

(c) Henrik I Christensen

Control of fingers?

- Models with and without tendons



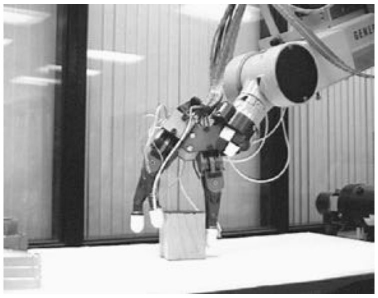
Source: Handbook of Robotics, 2010

Hand designs

- Early designs
  - MIT Utah Hand

  - DLR Generation I

Hand designs



- Stanford / JPL hand I

- DLR hand II

Newer hand designs

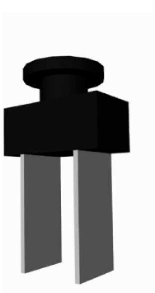
- Barrett Hand

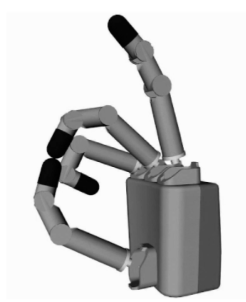
- Schunk SDH w. tactile arrays

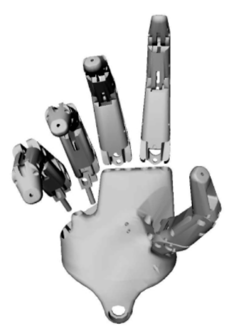
Newer hand designs

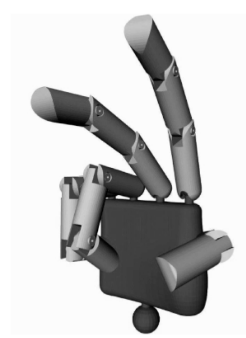
- Shadow hands

Newer hand designs



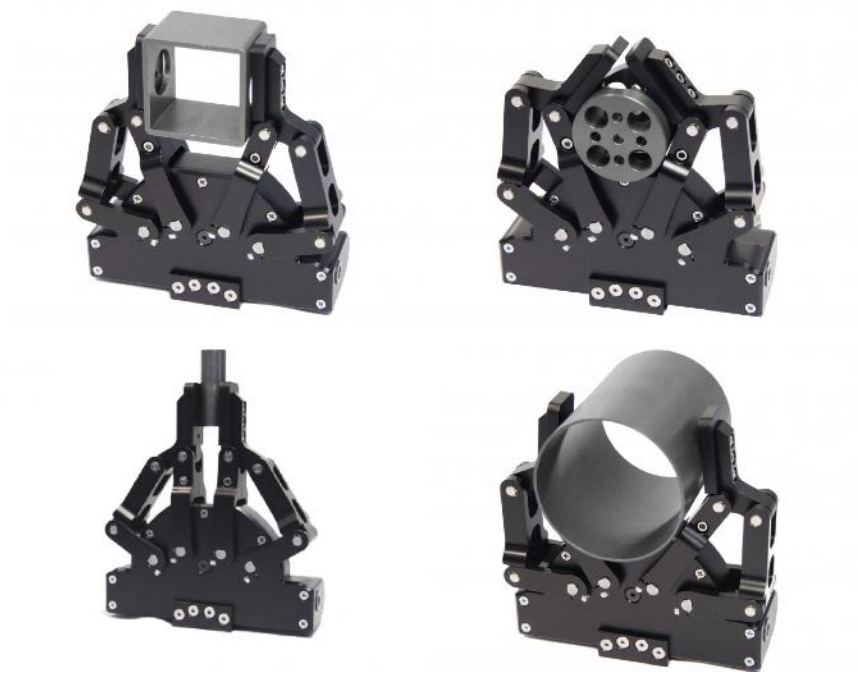




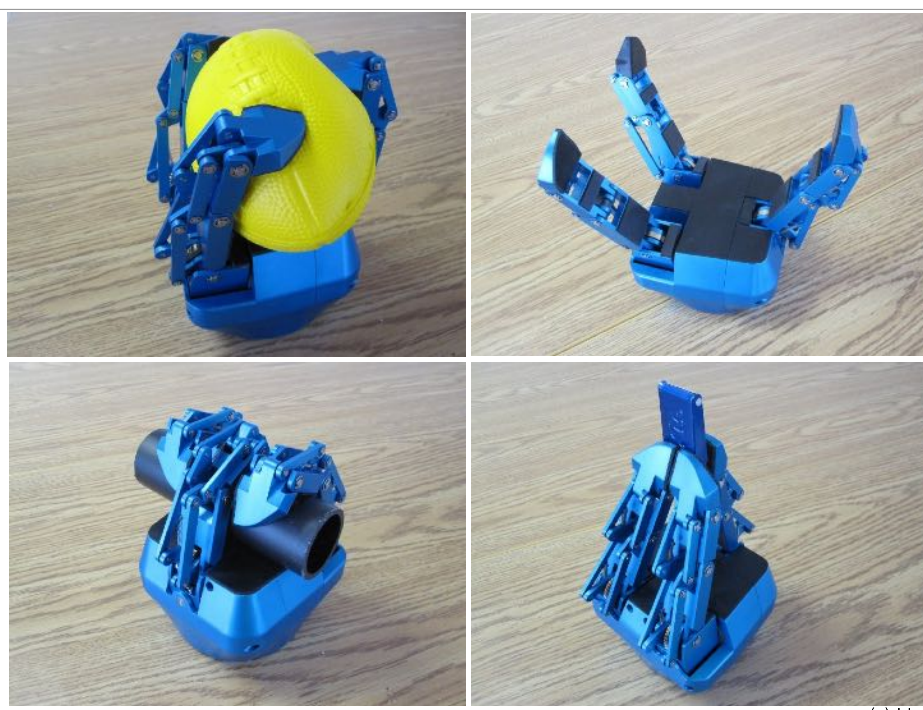


Recent hand designs

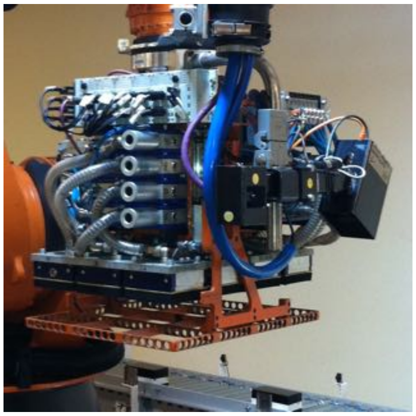
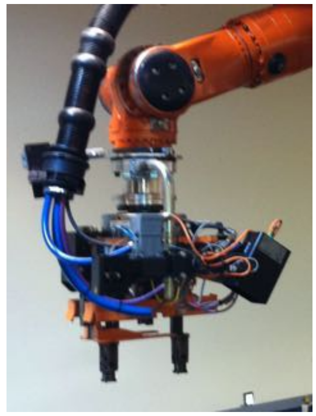
- Robotiq



Recent hand designs



Industrial gripper examples

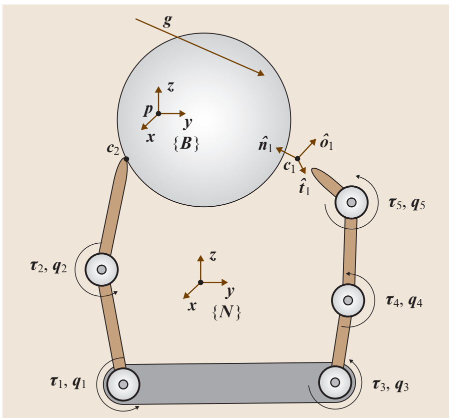






Grasping

- Models
- Grasp classification
- Performance
- Restraint analysis
- Examples

Grasp Modeling



Source: Handbook of Robotics, 2010

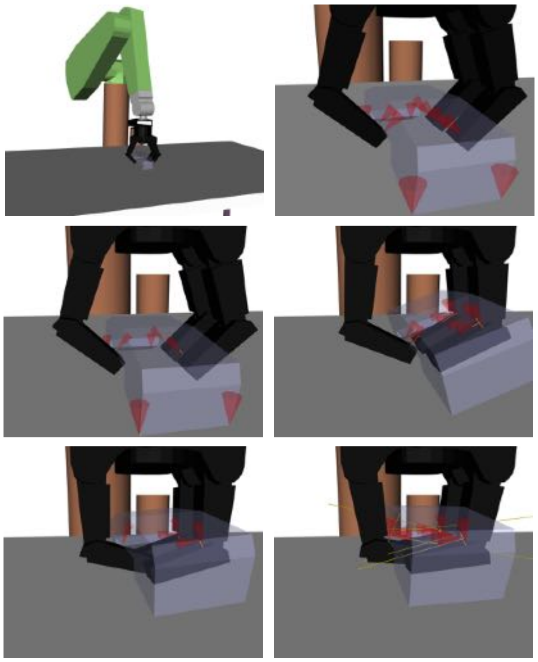
- How can we describe the dynamics of the body B with respect to the hand and its reference frame?
- Kinematic analysis
- Dynamic Analysis
- Can we constrain the dynamics?
- Remember manipulator designs from earlier?

Grasp Modeling

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

- We can define the Jacobian of the system and denote it by J
- We can further define a grasp matrix, G, that define the object-hand interaction and we have
- q as the state of the hand fingers and
- v is the velocity of the object

Grasp Dynamics



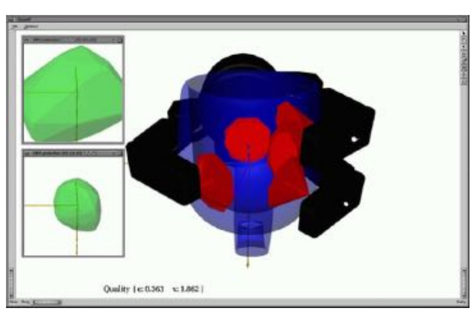
- Modeling interaction forces
- Using Columb friction model for object-object interaction
- Consideration of force generation to model the object dynamics

$$Q = M(q)\ddot{q} + C(q,\dot{q})\dot{q} + F(\dot{q}) + G(q) + J^T(q)g$$

- Fed into a physics based simulator
- Multiple physics based simulators
  - GraspIt
  - Blender
  - PhysX
  - ...

Grasp classification

- We can characterize grasps by the J and G matrices
  - If N(J) is non-trivial we can move the fingers around
  - If $N(G^T)$ is non-trivial then internal object motion is possible
  - If N(G) is non-trivial then the object is considered graspable.
  - A grasping system is said to be defective if $N(J^T)$ is non-trivial
- To visualize these aspects it is typical to consider the wrench space (6D) the space spanned by forces in XYZ and torques for the axes motion

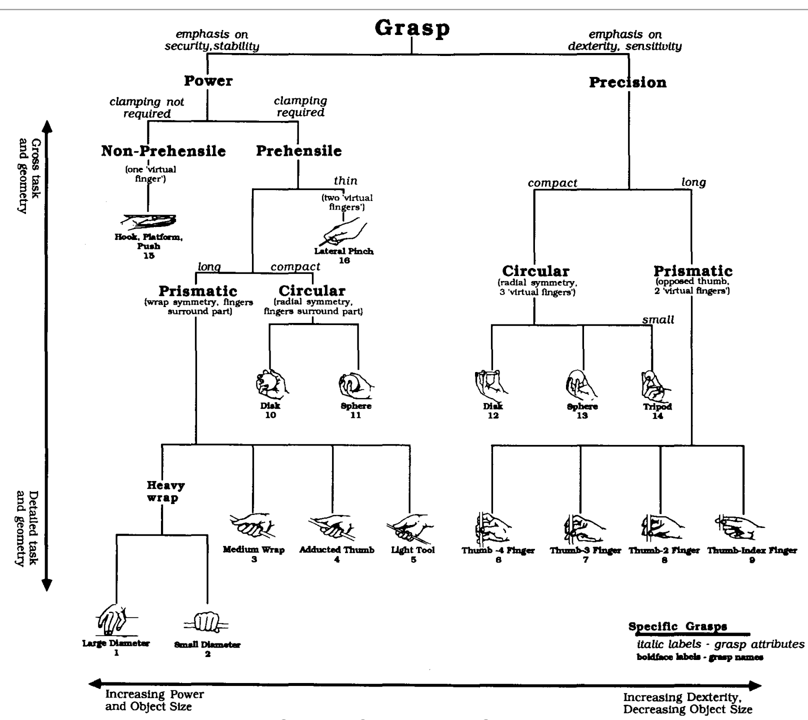


Grasp Measures

Compliance	What is the effective compliance (inverse of stiffness) of the grasped object with respect to the hand? The grasp compliance matrix is a function of grasp configuration, joint servoing, and structural compliances in the links, joints, and fingertips [6].
Connectivity	How many degrees of freedom are there between the grasped object and the hand? Formally, how many independent parameters are needed to completely specify the position and orientation of the object with respect to the palm [17]?
Force closure	Assuming that external forces maintain contact between the fingers and the object, is the object unable to move without slipping when the finger joints are locked? Formally, a grasp satisfies force closure if the union of the contact wrenches has rank 6 [17], [22].
Form closure	Can external forces and moments be applied from any direction without moving the object, when the fingers are locked? Formally, there is form closure, or complete kinematic restraint, if the intersection of all unisense contact twists is a null set. Thus seven frictionless point contacts are in general required to achieve form closure on a rigid body [13], [17].
Grasp isotropy	Does the grasp configuration permit the finger joints to *accurately* apply forces and moments to the object? For example, if one of the fingers is nearly in a singular configuration, it will be impossible to accurately control force and motion in a particular direction. Formally, the grasp isotropy is a function of the condition number of the grasp Jacobian matrix [12], [17]. Li and Sastry [14] define similar grasp quality measures that are functions of the singular values of the grasp Jacobian.
Internal forces	What kinds of internal grasp forces can the hand apply to the object? Formally, the internal grasp forces are the homogeneous solution to the equilibrium equations of the object. Thus internal grasp forces can be varied without disturbing the grasp equilibrium [12], [17].
Manipulability	While not consistently defined in the literature, a useful definition is: Can the fingers *impart* arbitrary motions to the object? Thus a manipulable grasp must have force closure and a connectivity of 6. In addition, the rank space of velocities due to the finger joints must span the space of velocities transmitted through the contacts [12].
Resistance to slipping	How large can the forces and moments on the object be before the fingers will start to slip? The resistance to slipping depends on the configuration of the grasp, on the types of contacts, and on the friction between the object and the fingertips [5], [10]–[12].
Stability	Will the grasp return to its initial configuration after being disturbed by an external force or moment? At low speeds, the grasp is stable if the overall stiffness matrix is positive definite [6], [21]. At higher speeds, *dynamic* stability must be considered [19].

Source: Cutkosky, TRO 1989

A Grasp Taxonomy (1989)



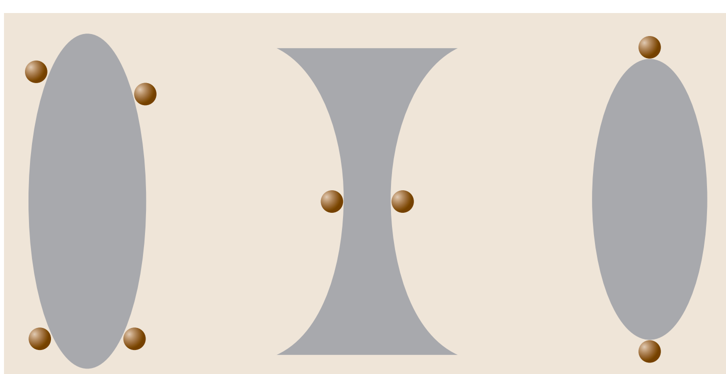
Source: Cutkosky, TRO 1989

Grasp Examples

Force closure

Precision grasp

Closure?

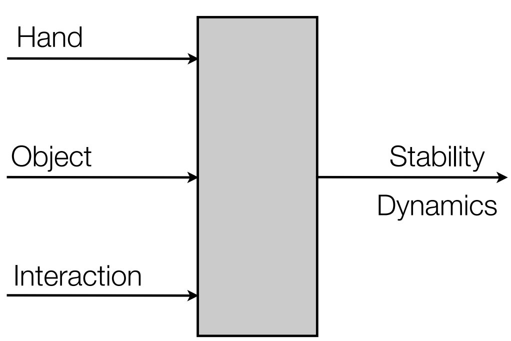


Grasp Analysis

- Most grasp analysis has been based on kinematic analysis
- Recent progress on physics based simulation has enabled dynamic evaluation
- Evaluation can be limited by limits in geometric knowledge
- Also symmetries poses a few challenges.
- Analysis of full geometry can also be limited by computational limitations
  - Objects with N faces might have upto $O(N^9)$ configurations

- There are tools available for analysis of grasps
  - Physics based models (GraspIt, PhysX, ...)

GraspIt (Columbia Univ)

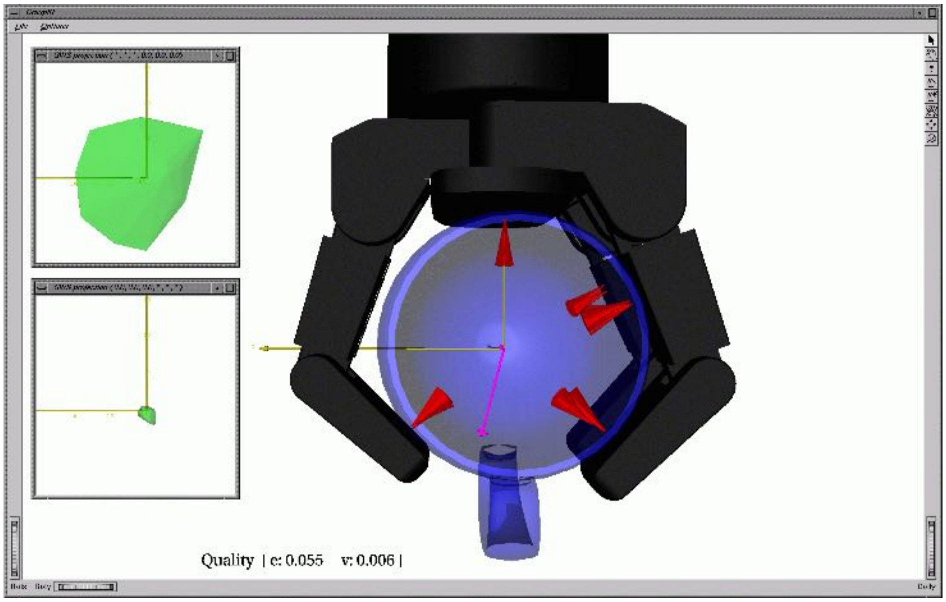


- Hand Geometry
- Object Geometry
- Arm Kinematics
- Friction / Object/Hand interaction

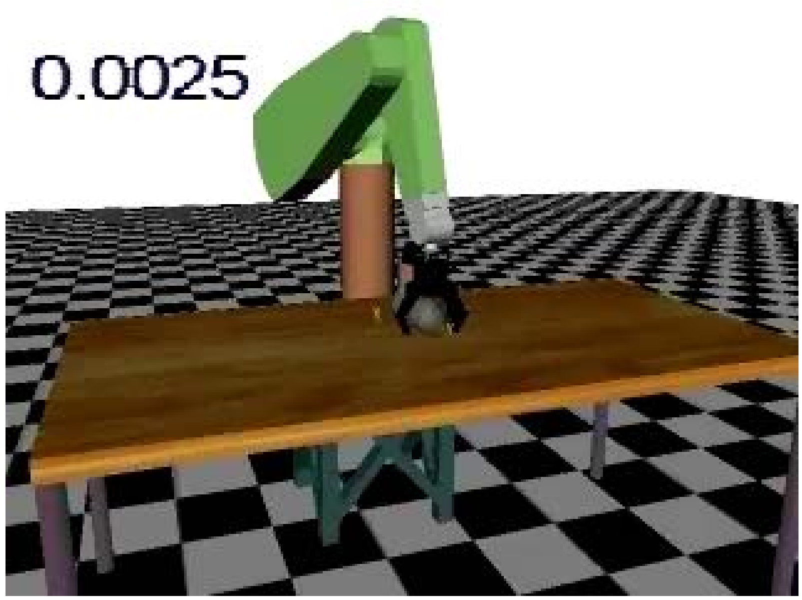
- Analysis of stability and possible interaction

- Based on a columb friction model

GraspIt

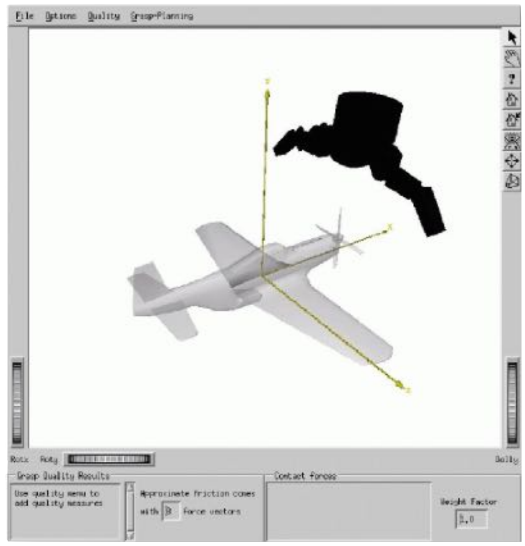


Example of glass grasping

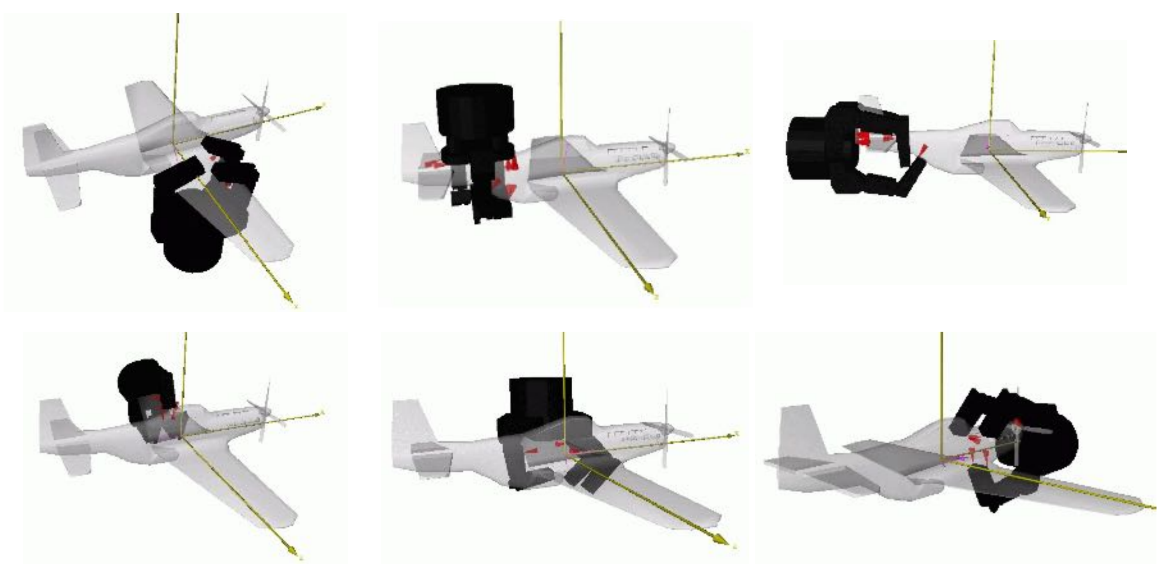


Consideration of stable grasps

- Analysis of possible contact points
- Evaluation of stable configurations
- Can be performed off-line



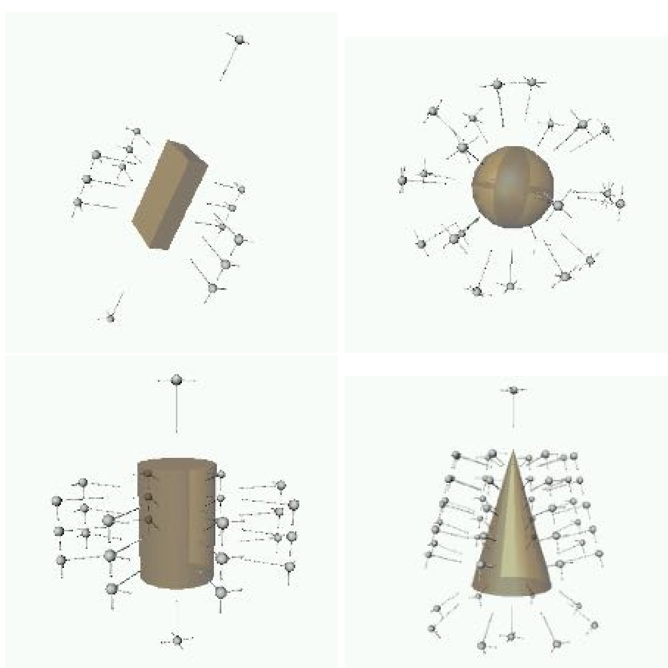
Grasp Strategies



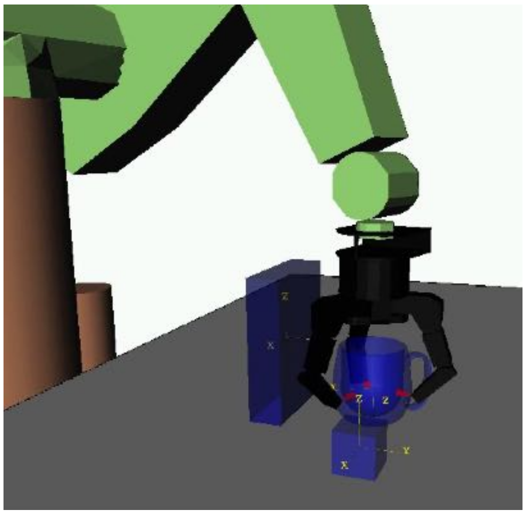
Source: Miller et al, IROS-2004

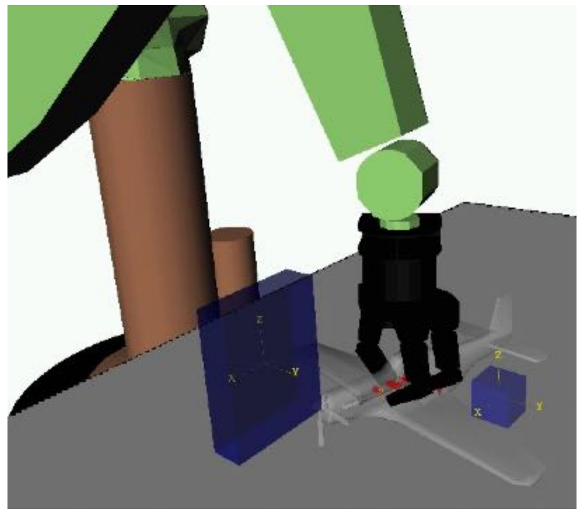
Generating grasp abstractions

Selection of grasp strategies



Selection of stable grasps





Use prototypical grasps to simplify

State of the art w. deep learning

Summary

- Hands
  - Gripper design is still very much an art form
  - Few standardized grippers for industry applications
- Physics based modeling is gaining popularity
  - Using physics models to understand behavior
  - Models of friction and object-object interaction
- A variety of tools available for grasp evaluation
- Few benchmarks available for industry grade problems