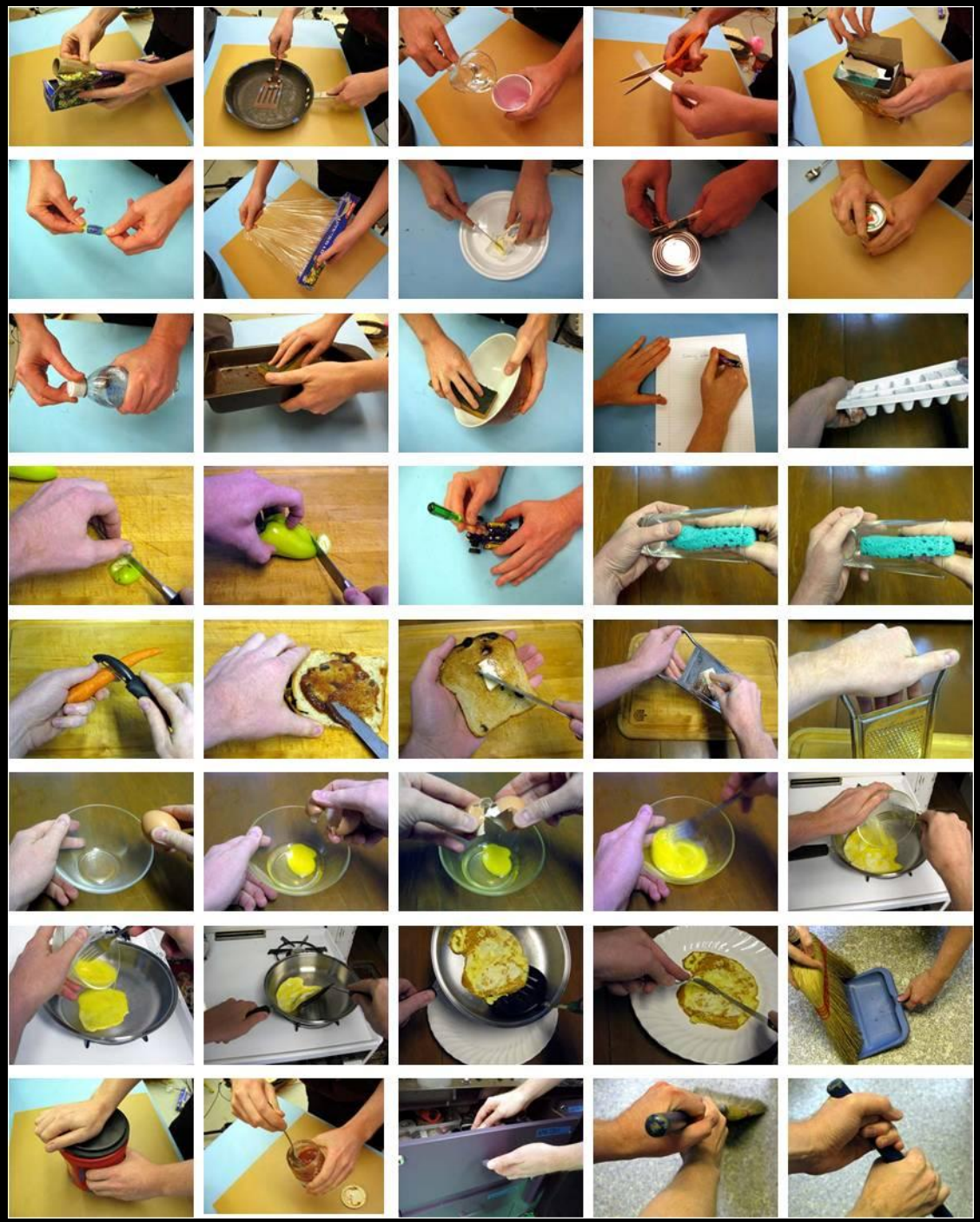
Outline

- Existing hands
  - Robot hands of the ‘80s
  - Commercial hands
  - Research hands
  - Prosthetics
- Design issues
  - Kinematics
  - Compliance
  - Sensing
  - Actuation
  - Control
  - Robustness
- Evaluation
- Discussion

Design Issues - Kinematics

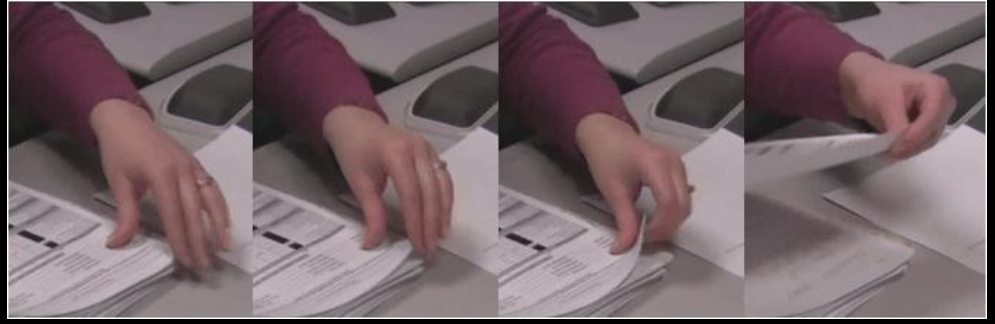
How many / which degrees of freedom?

How many / which *controlled* degrees of freedom?



Design Issues - Kinematics

How many / which degrees of freedom?

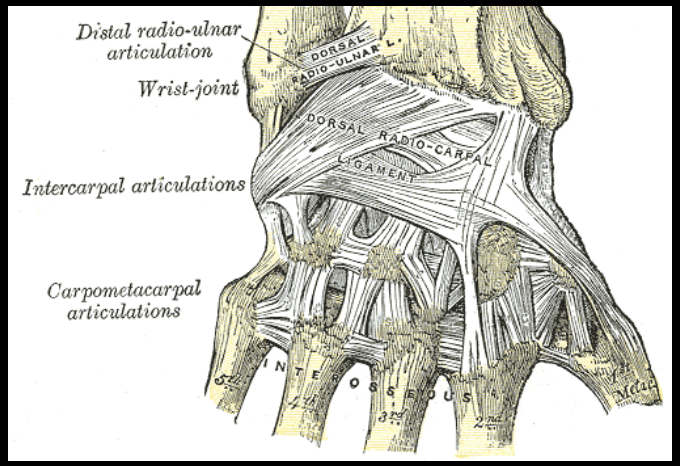


Design Issues - Kinematics

How many / which degrees of freedom?

Human Hand Kinematics

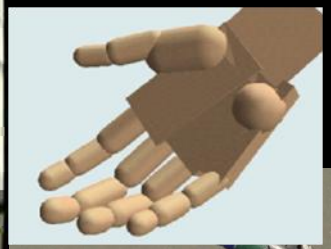
finger CMC degrees of freedom (“palm flex”)



fingers curl inward

large pad-to-pad contact area thumb with fingers

passive twist allows finger pads to make better contact with object



palm geometry aids power grasping

Design Issues - Kinematics

How many / which degrees-of-freedom?

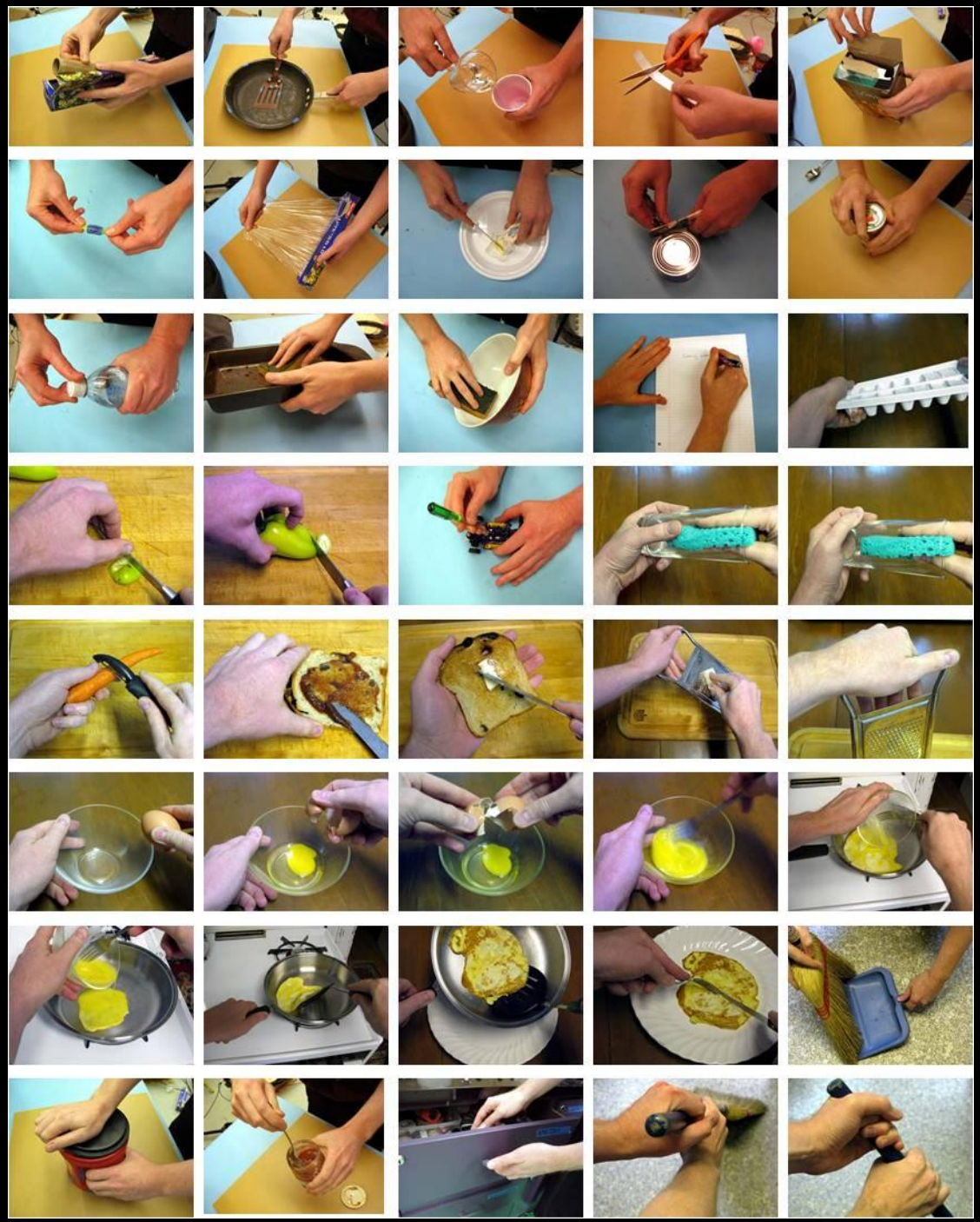
- substantial flexibility is needed to conform to object surfaces and perform precise manipulations

How many / which *controlled* degrees-of-freedom?

- underactuated hands can grasp objects well due to many good design ideas
- fewer motors may limit ability to manipulate objects and may result in loss of breadth in ability to apply forces
- distinction between dominant and non-dominant hand?

Design Issues - Kinematics

Non-dominant hand often acts as fixture or jig



Design Issues - Compliance

Intrinsic compliance in joints aids withstanding impacts

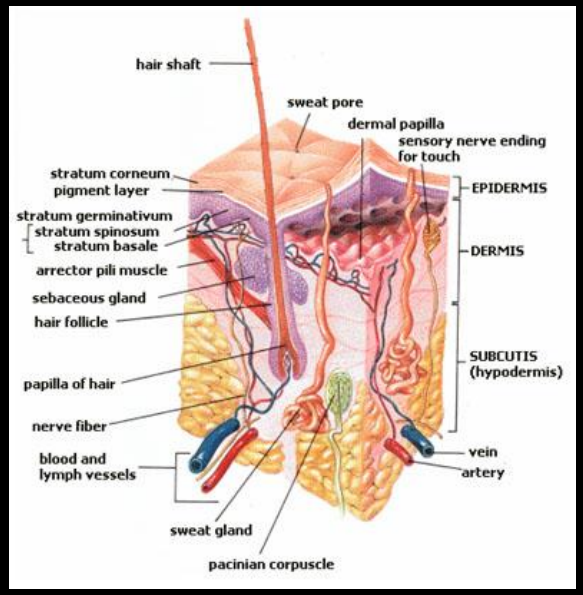
For low stiffness movement, damping or compensation for arm motion is needed

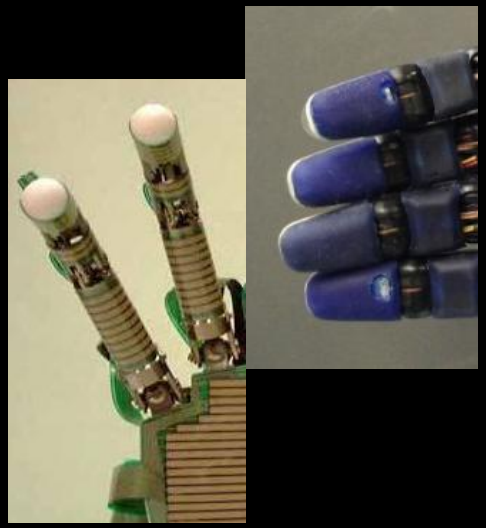
Hand stiffness should increase with increasing applied force for strong grip

Skin material should support low friction slip with low force and higher friction grip with higher force

Design Issues - Sensing

nerve endings	temperature, pain	
Meissner corpuscles	velocity, light touch	
Merkel discs	pressure, low freq	FSR, QTC, etc.
Ruffini corpuscles	pressure, skin stretch	
Pacinian corpuscles	acceleration, high freq	
Golgi tendon organs	tendon stretch	strain gauges
Proprioceptors	position	hall effect, optical...

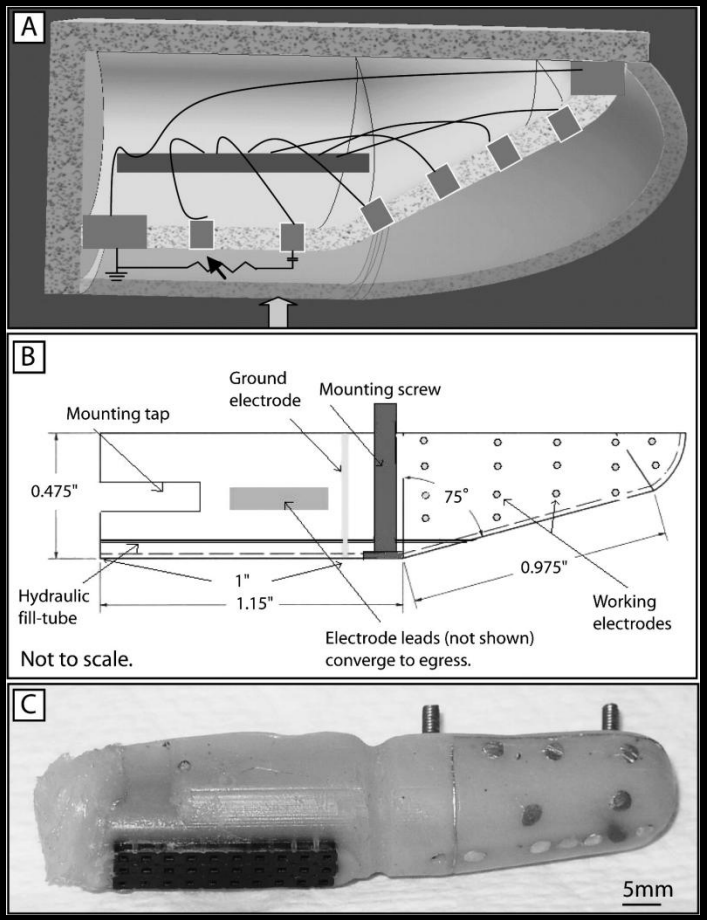




Design Issues - Sensing

Compensating with position sensors?

Electric field based tactile sensor (Gerald Loeb, USC)



Electric field imaging (Josh Smith, Intel)

Design Issues - Actuation

Pneumatic muscles vs. electric motors vs. SMA

- SMA technology not yet out of research labs
- even Shadow is going to electric motors
- thinking heading toward DC motors with elastic elements
- goals: compliance at impact / stiffness increasing with force

Tendons vs. linkages

- tendons have appeal but still have wear problems

Will we solve the weight problem by requiring fewer motors?

Design Issues – Control

It has been observed that muscle coordination patterns switch from position control to isometric force control ~65 seconds before contact

For humans, forces modulated by sensor feedback w/in 70ms

Typists may have 100-200ms interval between keystrokes

Pianists may have 80-100ms interval between notes

Typical latencies in a robotic hand/arm system may be 40ms

A hand moving at a typical reaching speed of 1m/s will move 4cm in 40ms

Design Issues - Robustness

Package sensors into the skeleton (Dollar and Howe, Loeb)

Simplicity

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Evaluation

Task-based?

- 200 everyday activities performed with the hand(s)

Hand therapists also struggle with this issue

Physical demands approach:

- test ability to perform specific job related tasks
- test ability to perform benchmark tasks of daily living

Coordination or dexterity assessment:

- standardized tests aimed at dexterity generically

Functional assessment:

- holistic view of hand function

Personal Constraints

Physical Status
Musculoskeletal; Neurological
- functioning range of motion of fingers, hand
- sensitivity/pain/edemas
- strength

Psychological Status
- perceptual/cognitive/developmental limitations
- motivation
- self perception of hand functioning
- socio-cultural framework

Hand Roles

Unimanual
- right
- left

Bimanual
- Undifferentiated (simultaneous, alternate)
- Role differentiated

Object Related Hand Actions

Reach
- trunk stable
- near/far
- cross midline
- upward and forward

Grasp
- whole hand
  - palmer
  - hook
- thumb opposition
  - all digits
  - tripod
  - pincer

Manipulate Objects
- direct or indirect (tool)
- whole/part of hand/fingers
  - manual exploration
  - stabilize, orient
  - transport, guide, trace
  - insert, attach, push, rotate
  - remove, pull, release

Task Parameters

Object
- size, weight
- shape, texture
- relative spatial position
- number of objects

Movement Pattern
- single, discrete action
- repeated discrete actions
- continuous actions
- sequence of different actions

Performance Demands
- spatial: target, path, direction
- temporal: speed, rhythm, adaptive
- force: amount, modulation
- endurance
- physical environment

Final Observations

The best demos we have by far are teleoperation demos from highly trained users

Users of prosthetic hands appear to make extra use of the environment, second hand, arm, and body to shape the prosthetic hand for proper grasping

People are compensating for deficits in current hand sensor technology and control strategies

Discussion Points

Humanlike or other?

How many and which controlled DoF?

How should we evaluate potential hand designs?

tasks, kinematics, dynamics, sensing, control all affect results

What new sensor / actuation technology is needed?

What new developments in control strategies are needed?