ME 327: Design and Control of Haptic Systems
Spring 2020

Lecture 12: Kinesthetic haptic devices: multi-DOF rendering

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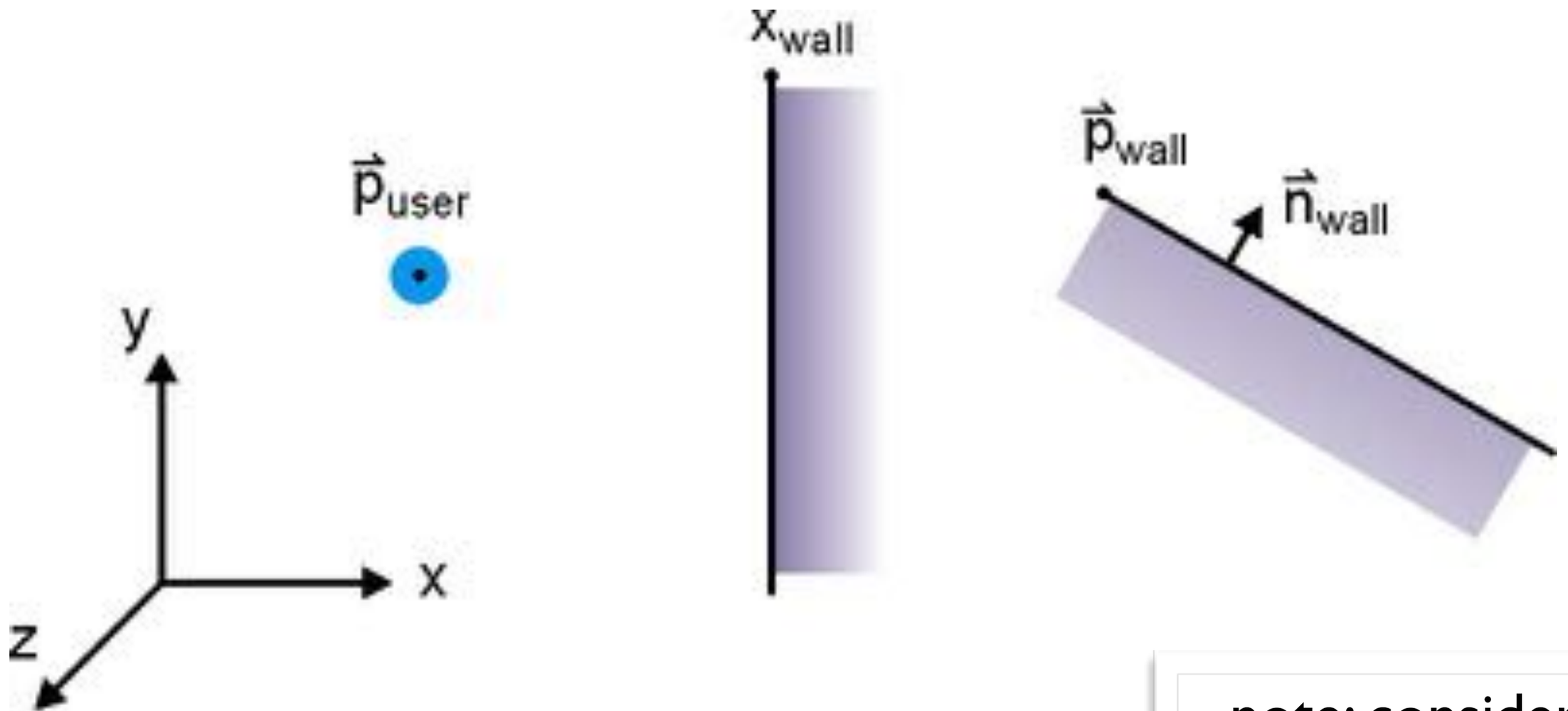
Stanford University

rendering algorithms

Coordinate Systems



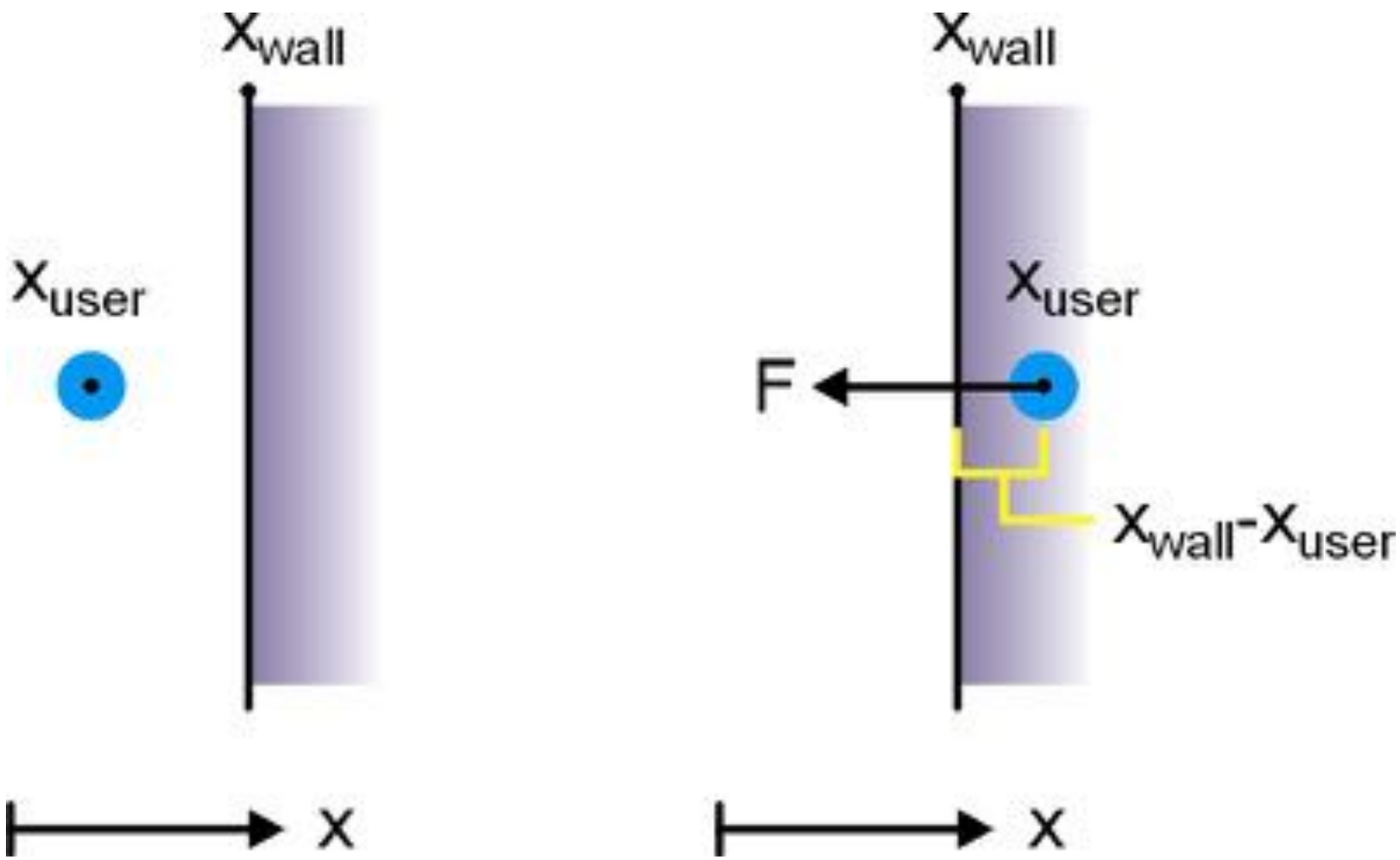
$$\vec{p}_{user} = [x_{user}, y_{user}, z_{user}]$$

note: consider singularities in the workspace!

Wall aligned with axis

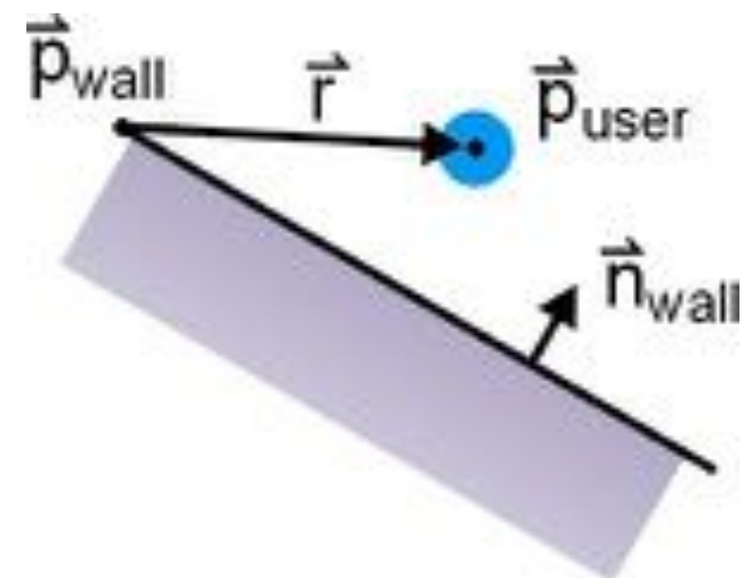
$$\text{If } x_{user} > x_{wall}, F = k(x_{wall} - x_{user})$$

$$\text{stiffness } k > 0$$



Non-aligned wall

$$\vec{r} = \begin{bmatrix} x_u - x_w \\ y_u - y_w \\ z_u - z_w \end{bmatrix}$$

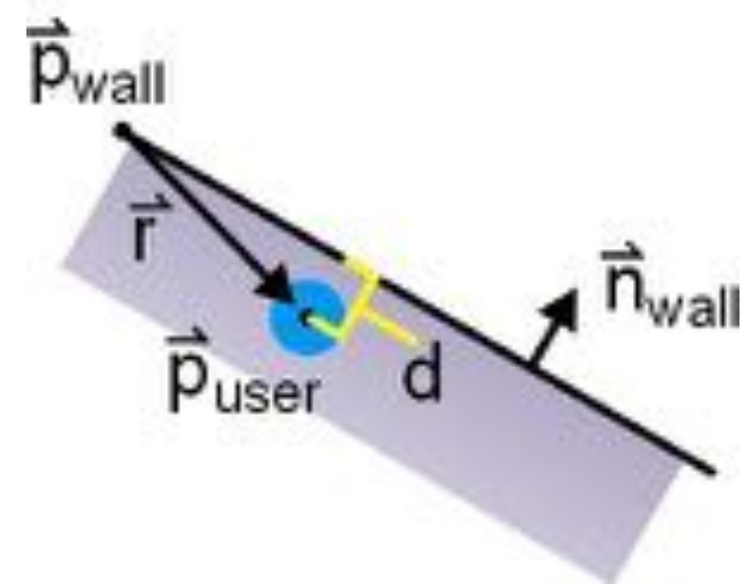


$$\text{if } (\vec{r} \cdot \vec{n}) > 0 \rightarrow \text{no collision,}$$

$$\text{if } (\vec{r} \cdot \vec{n}) < 0 \rightarrow \text{collision}$$

$$\mathrm{d} = \left| (\vec{r} \cdot \vec{n}) \cdot \vec{n} \right|$$

$$F = kd\vec{n}$$



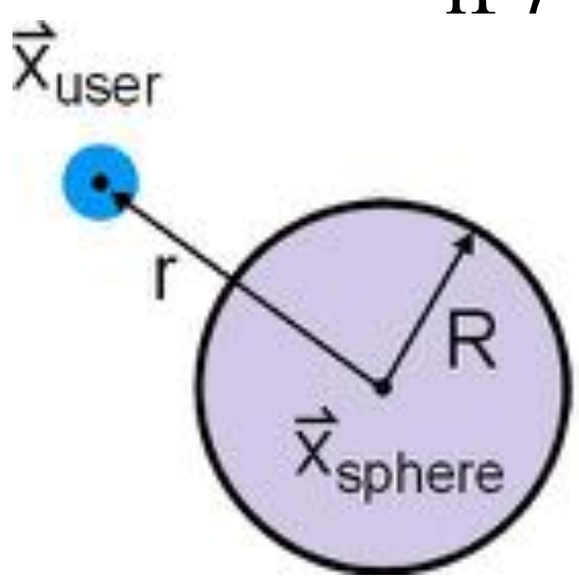
(does this work? Check yourself)

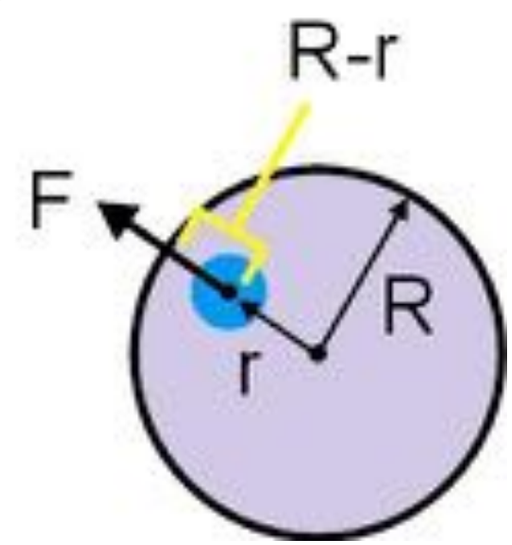
Outside a sphere

$$r = \sqrt{(x_u - x_s)^2 + (y_u - y_s)^2 + (z_u - z_s)^2}$$

$$\hat{r} = \frac{1}{r}\begin{bmatrix} x_u - x_s \\ y_u - y_s \\ z_u - z_s \end{bmatrix}$$

$$\text{if } r < R, F = k(R - r)\hat{r}$$





Inside a box

$$F_x = 0$$

$$F_y = 0$$

$$\text{if } x_{user} > x_{wall-max}$$

$$\quad F_x = F_x + k(x_{wall-max} - x_{user})$$

$$\text{if } x_{user} < x_{wall-min}$$

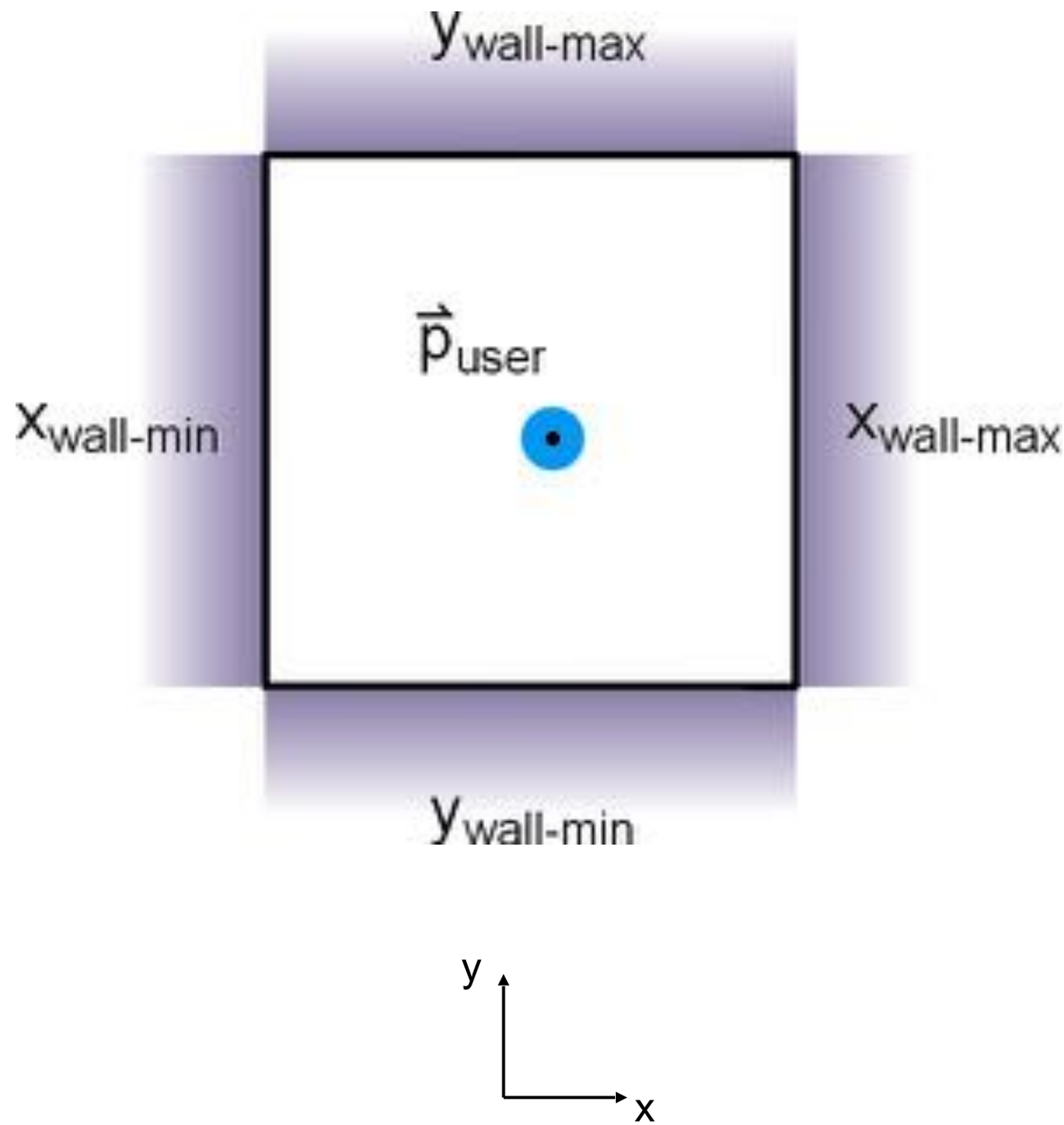
$$\quad F_x = F_x + k(x_{wall-min} - x_{user})$$

$$\text{if } y_{user} > y_{wall-max}$$

$$\quad F_y = F_y + k(y_{wall-max} - y_{user})$$

$$\text{if } y_{user} < y_{wall-min}$$

$$\quad F_y = F_y + k(y_{wall-min} - y_{user})$$

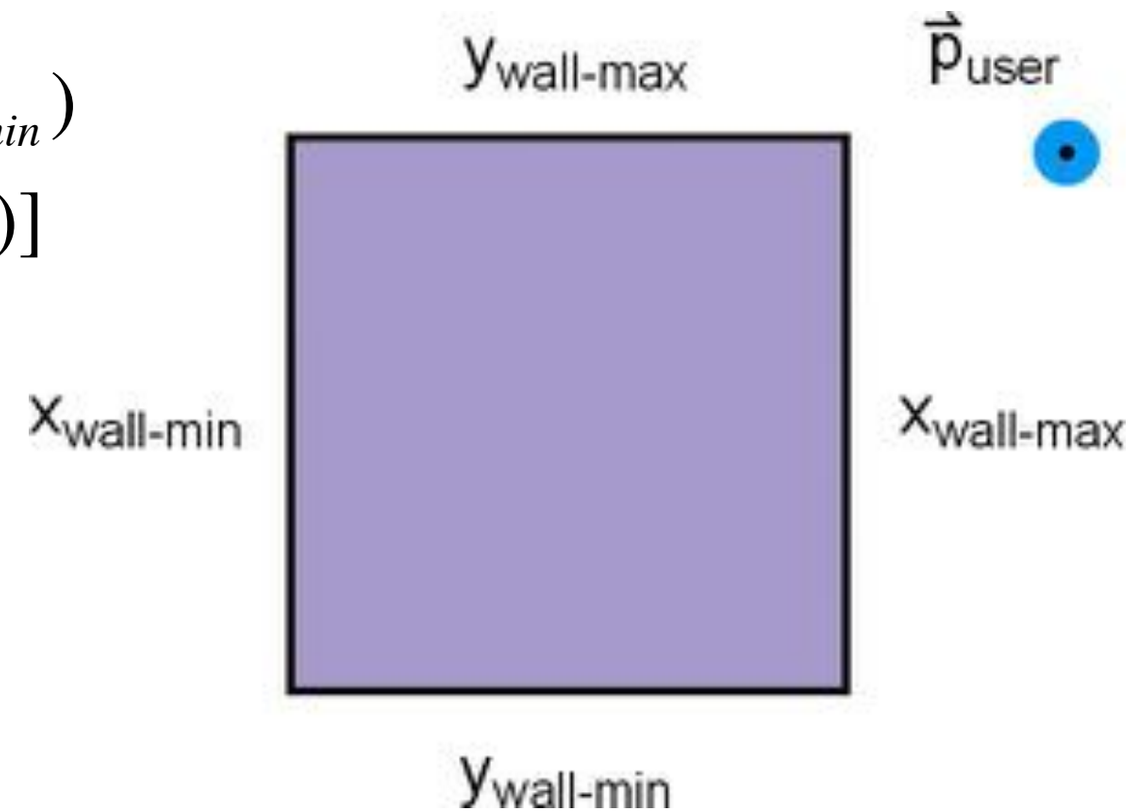


Outside a box

$$F = 0$$

$$\text{if } [(x_{user} < x_{wall-max}) \ \& \ (x_{user} > x_{wall-min})$$
$$\&(y_{user} < y_{wall-max}) \ \& \ (y_{user} > y_{wall-min})]$$

Then… what force should be displayed??

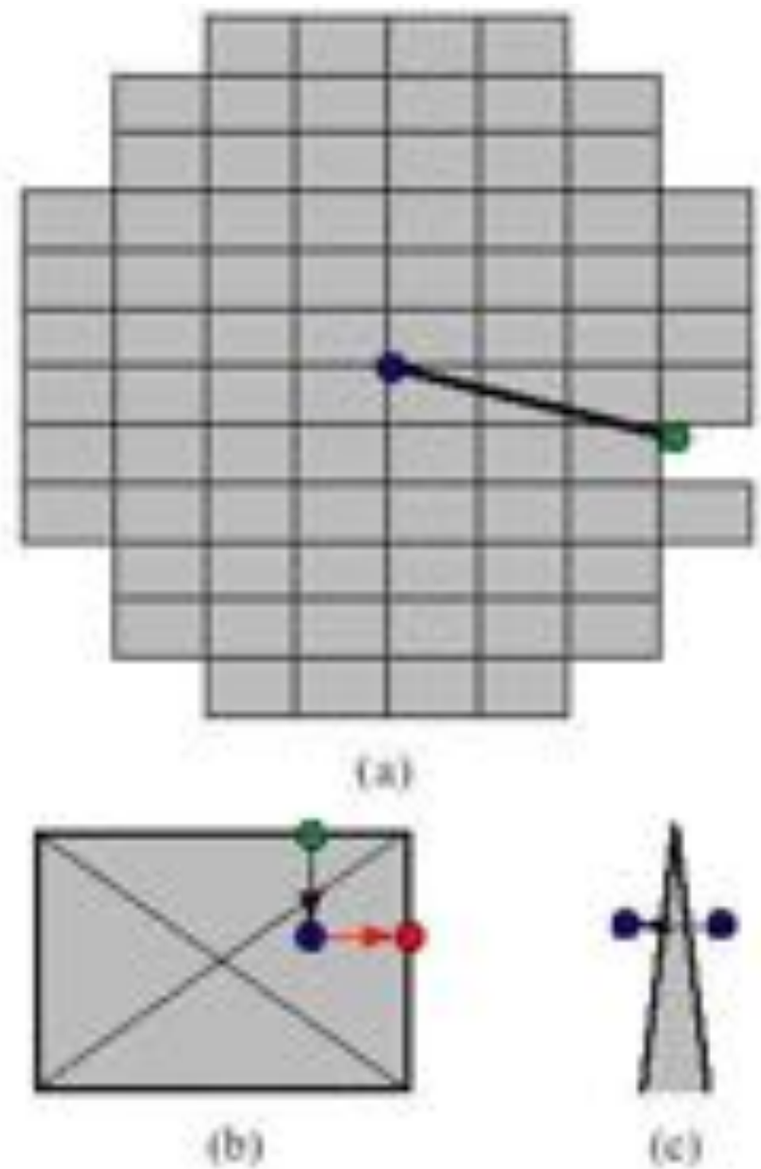


Limitations of "penalty-based" methods

(a) Lack of locality

(b) Force discontinuities

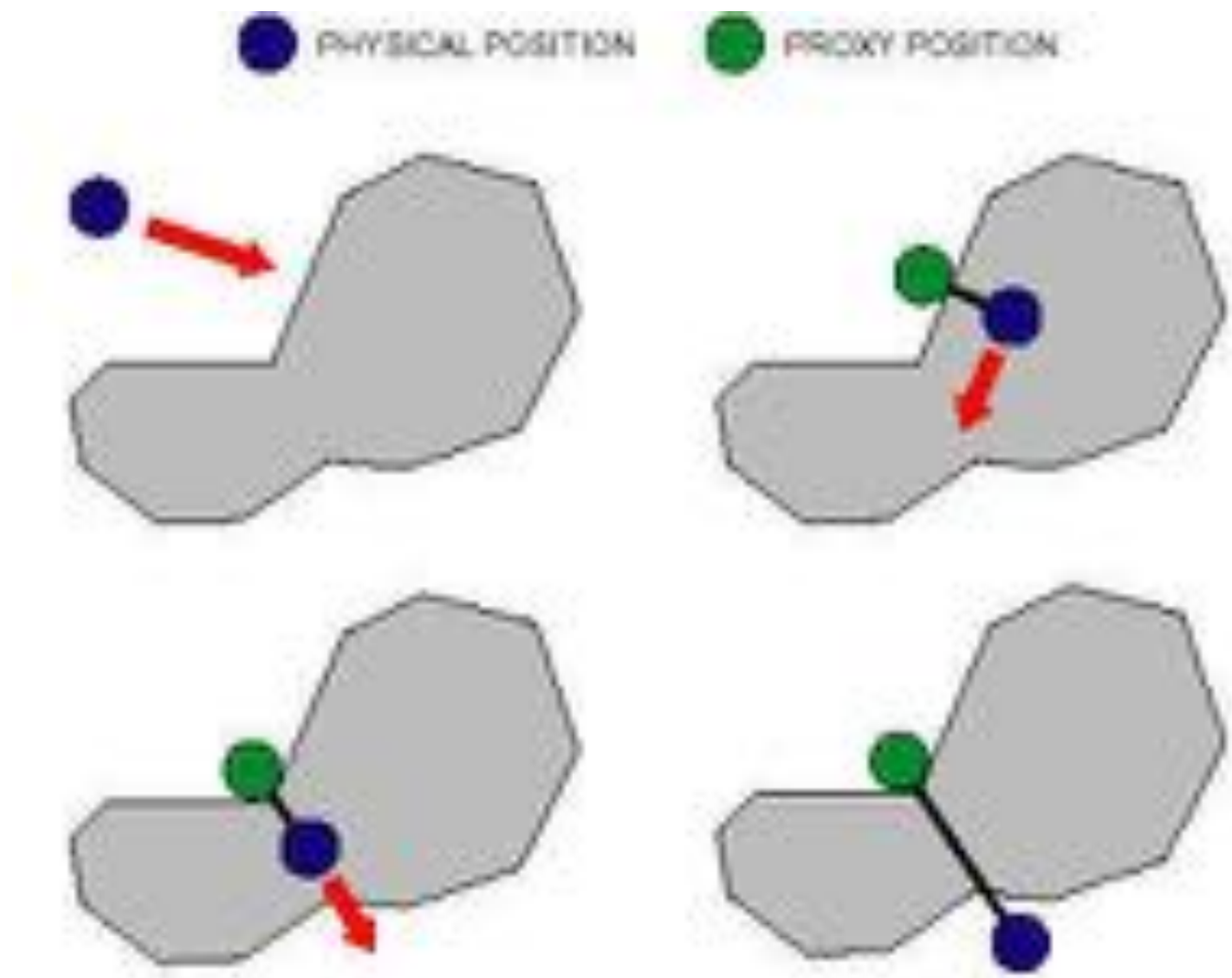
(c) "Pop-thru" of thin objects



Ruspini, et. al (1997)

The proxy object

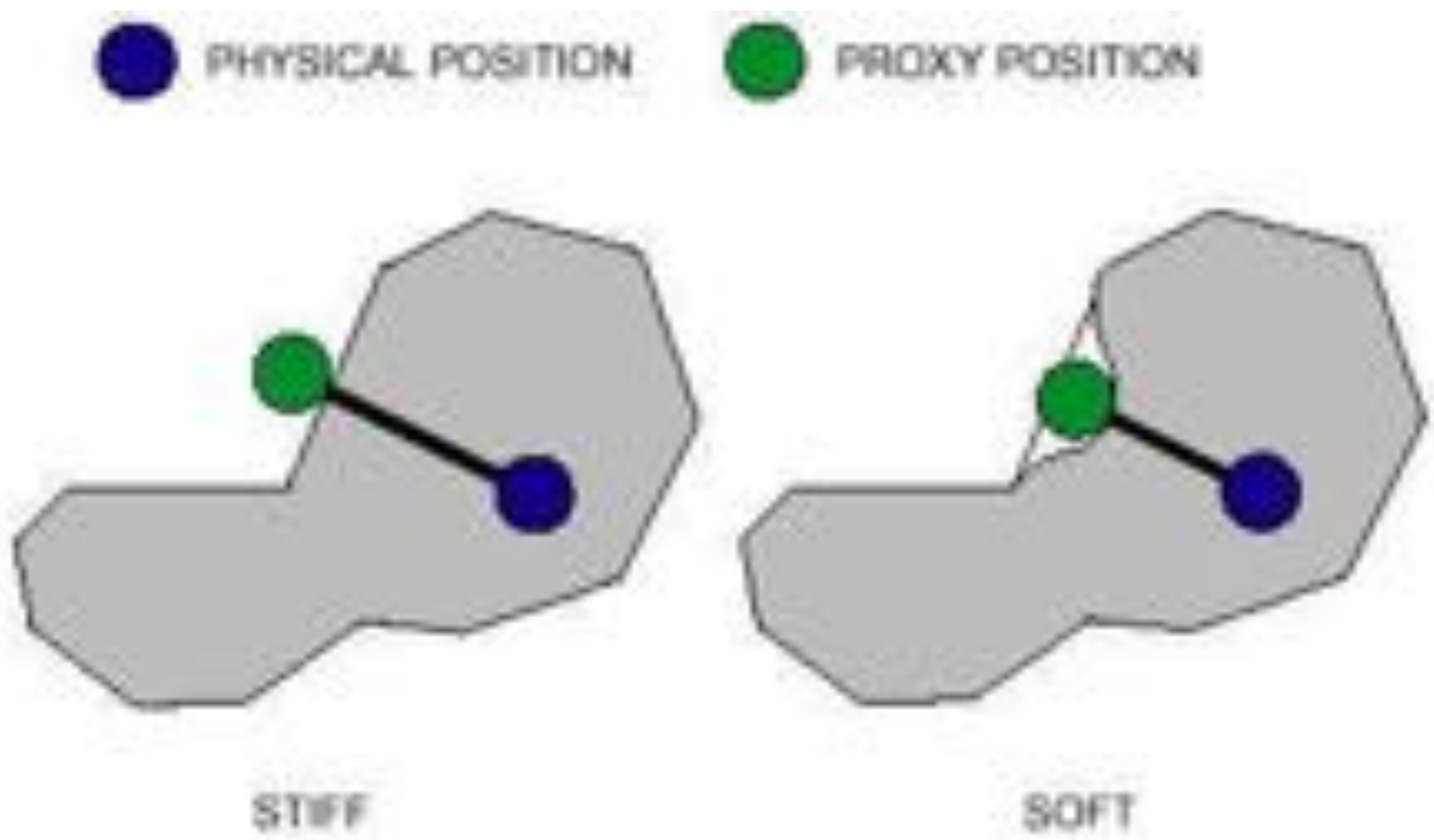
- Keep track of virtual object on the surface
- A related concept is the “God Object” (Zilles & Salisbury 1997)



Ruspini, et. al (1997)

What you feel

Object has limited stiffness, but it is not "deformable" in a global sense unless you explicitly program it that way



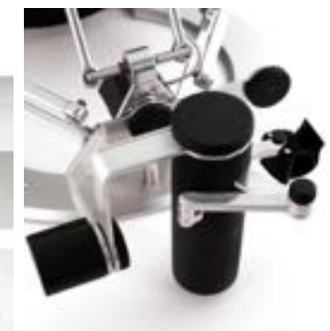
a commercial 3-DOF device

Slides from Francois Conti about
Force Dimension
and the Novint Falcon
(2014)

Designing Commercial Haptic Devices







ME 327
05/09/2014

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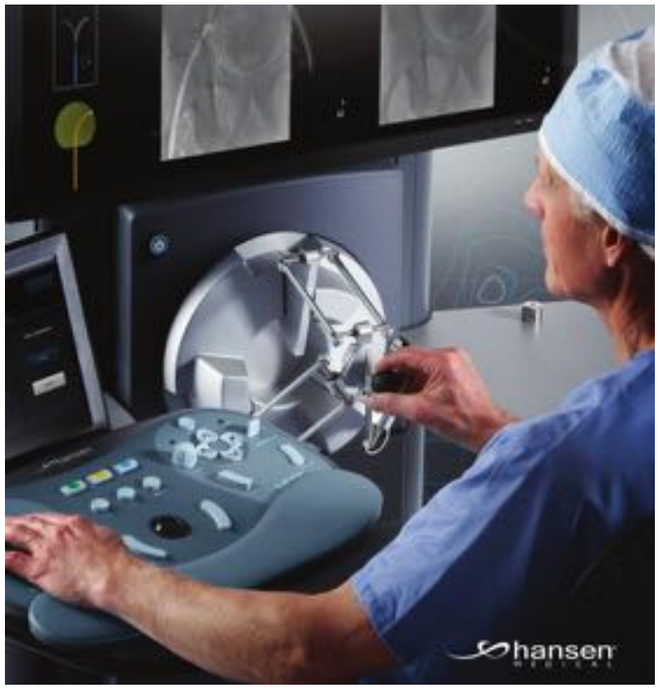
Commercial Haptic Devices

A 10 Year Journey



Developing a Product

Industrial Design

omega.3
Force Dimension

3D Consumer Haptic Interfaces

Design Challenges

omega.3
$20’000

Falcon
$200

3D Consumer Haptic Interfaces

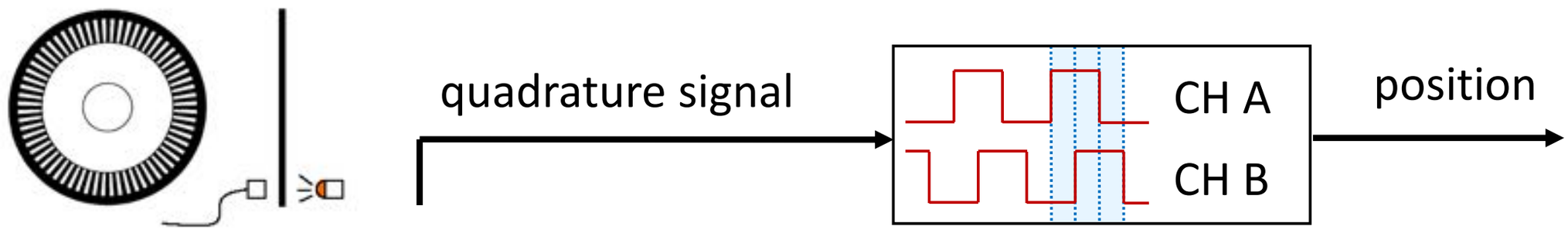
Design Challenges

Maxon Motor
$150

Johnson Motor
$1.50

Position Sensors

Optical Encoders



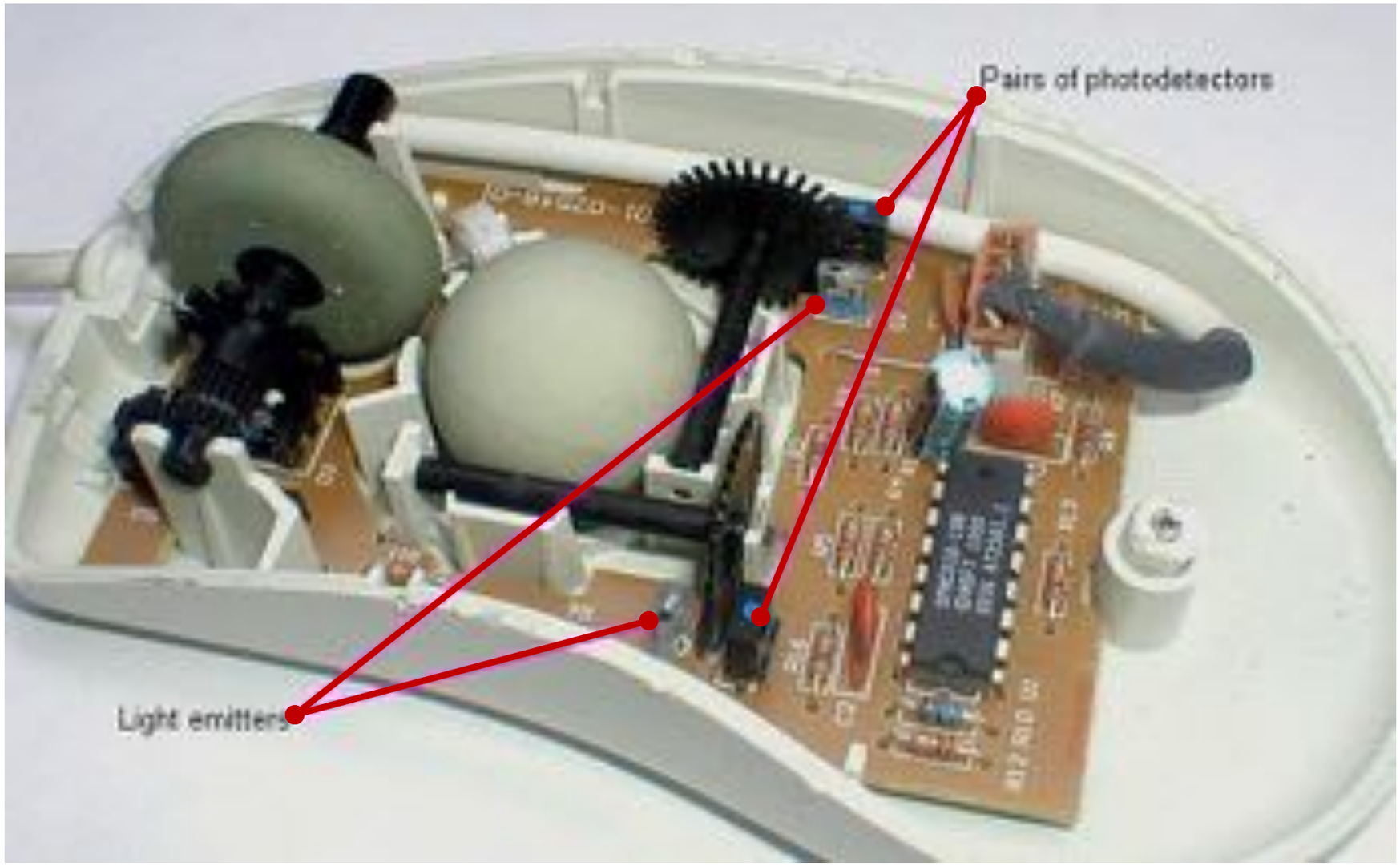
optical encoder

Phantom
Sensable Technologies

- **Resolution**
  1000 increments per revolution.
- **Low signal noise**
  Signal remains digital. No analog conversion.
- **Contact**
  Frictionless. No contact between optical disc and sensor.
- **Cost**
  30-40 US$ for an encoder and counter.

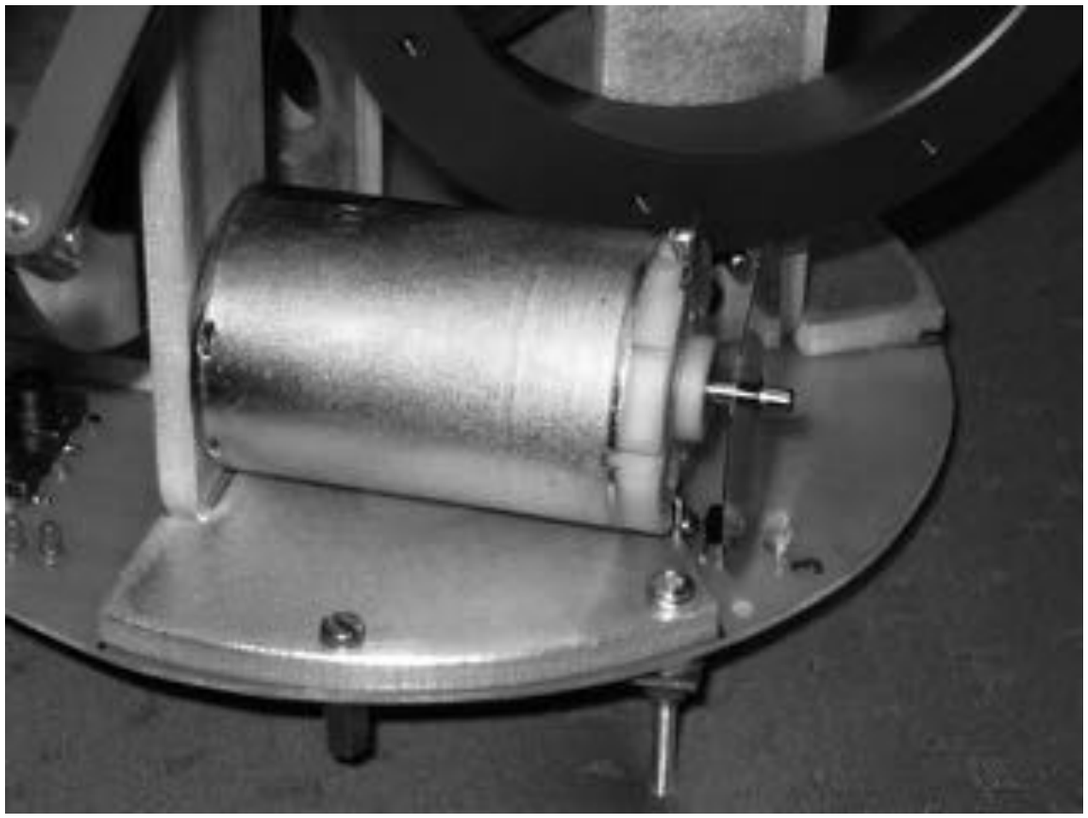
Position Sensors

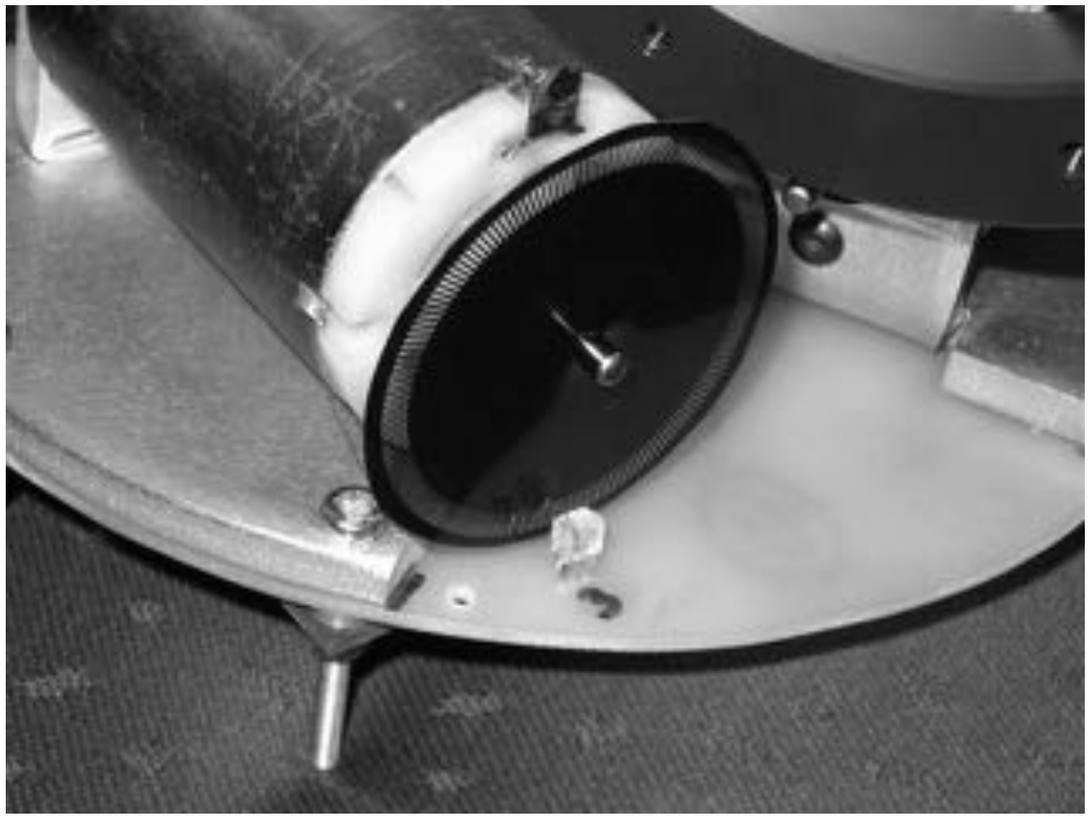
Optical Encoders



Position Sensors

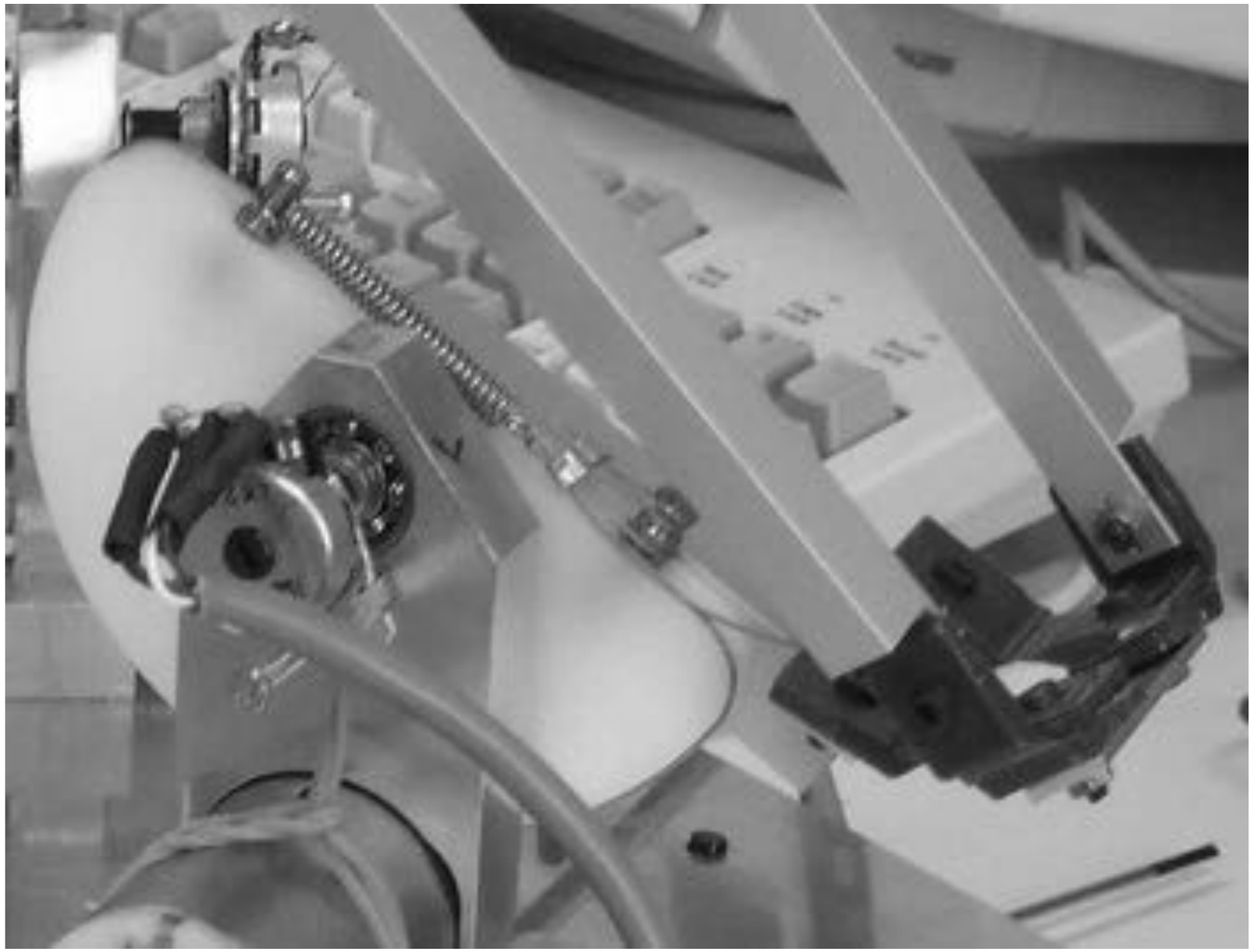
Optical Encoders





Mechanical Design

Articulated Systems

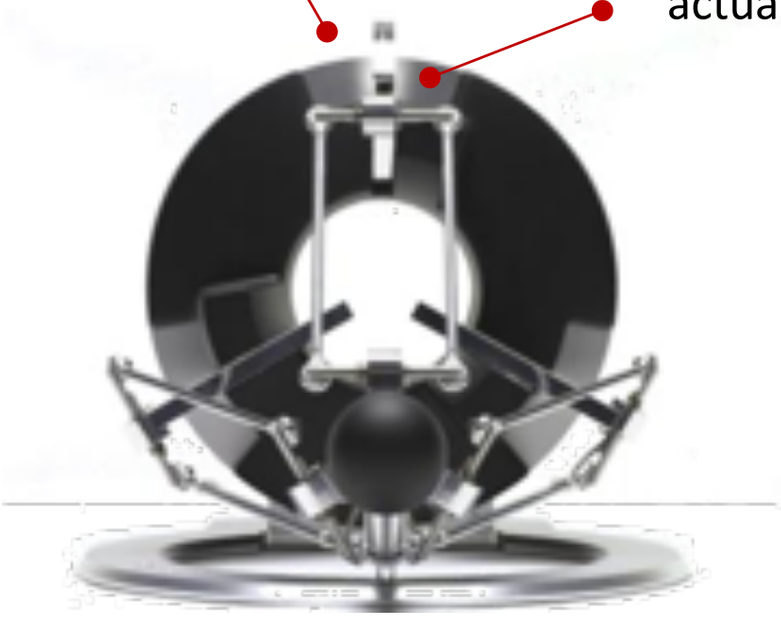


Communication Interface

Information Transfer

position sensing

actuation



force output

information transfer

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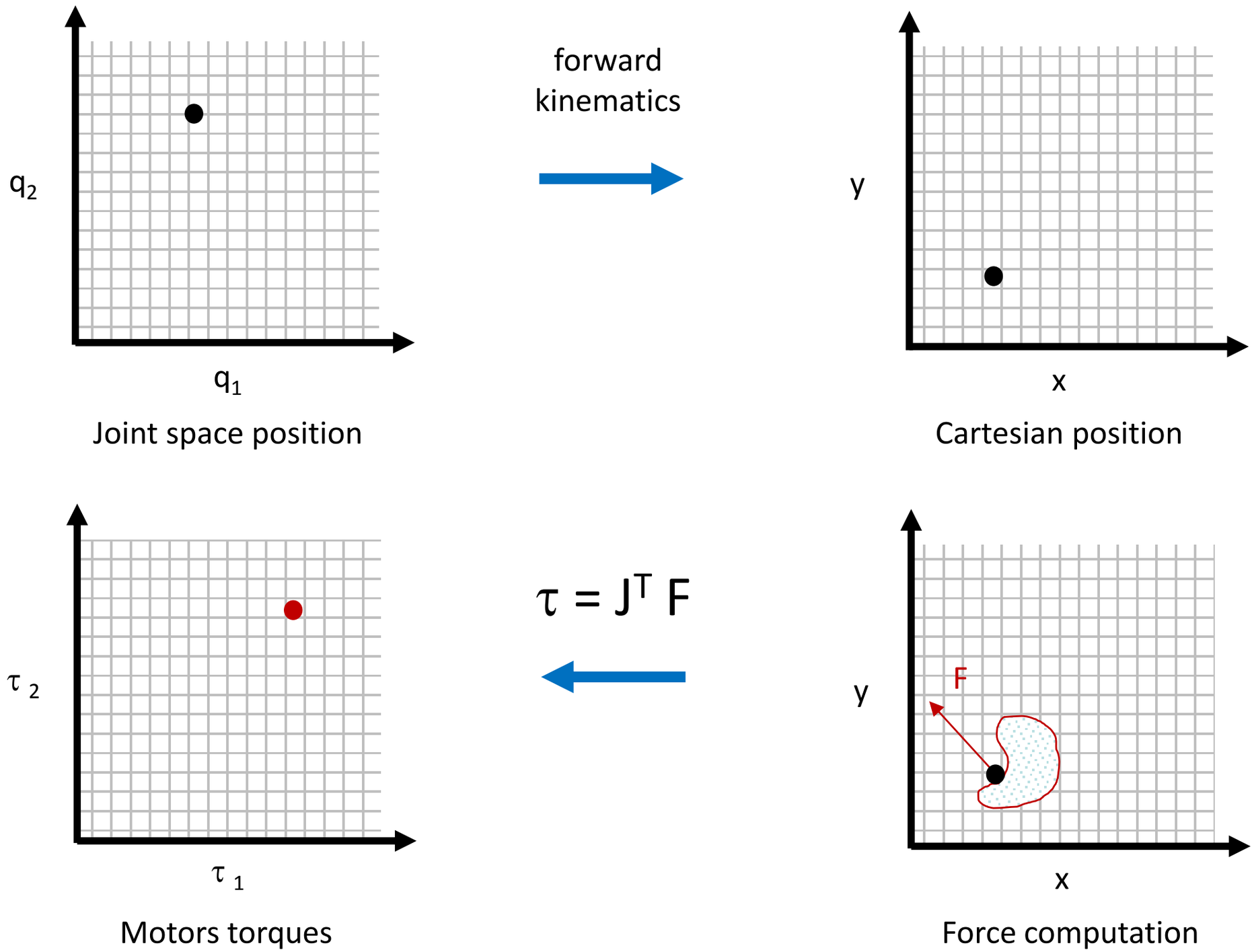
receiving position data

computing forces

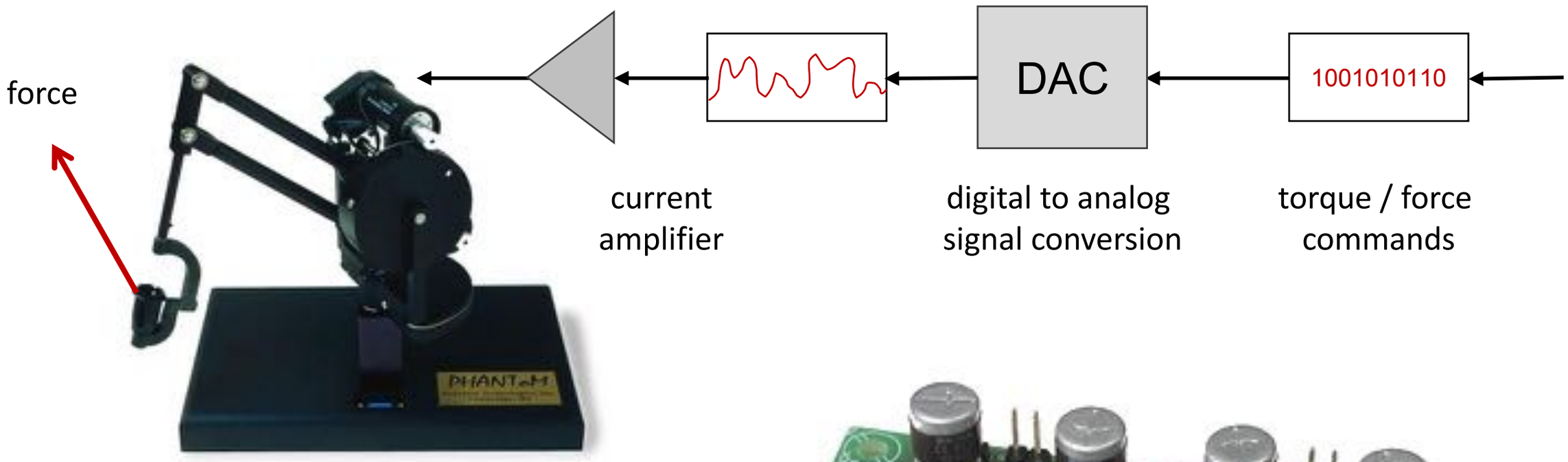
Computation

Position and Force



Actuation Stage

Current Amplifiers



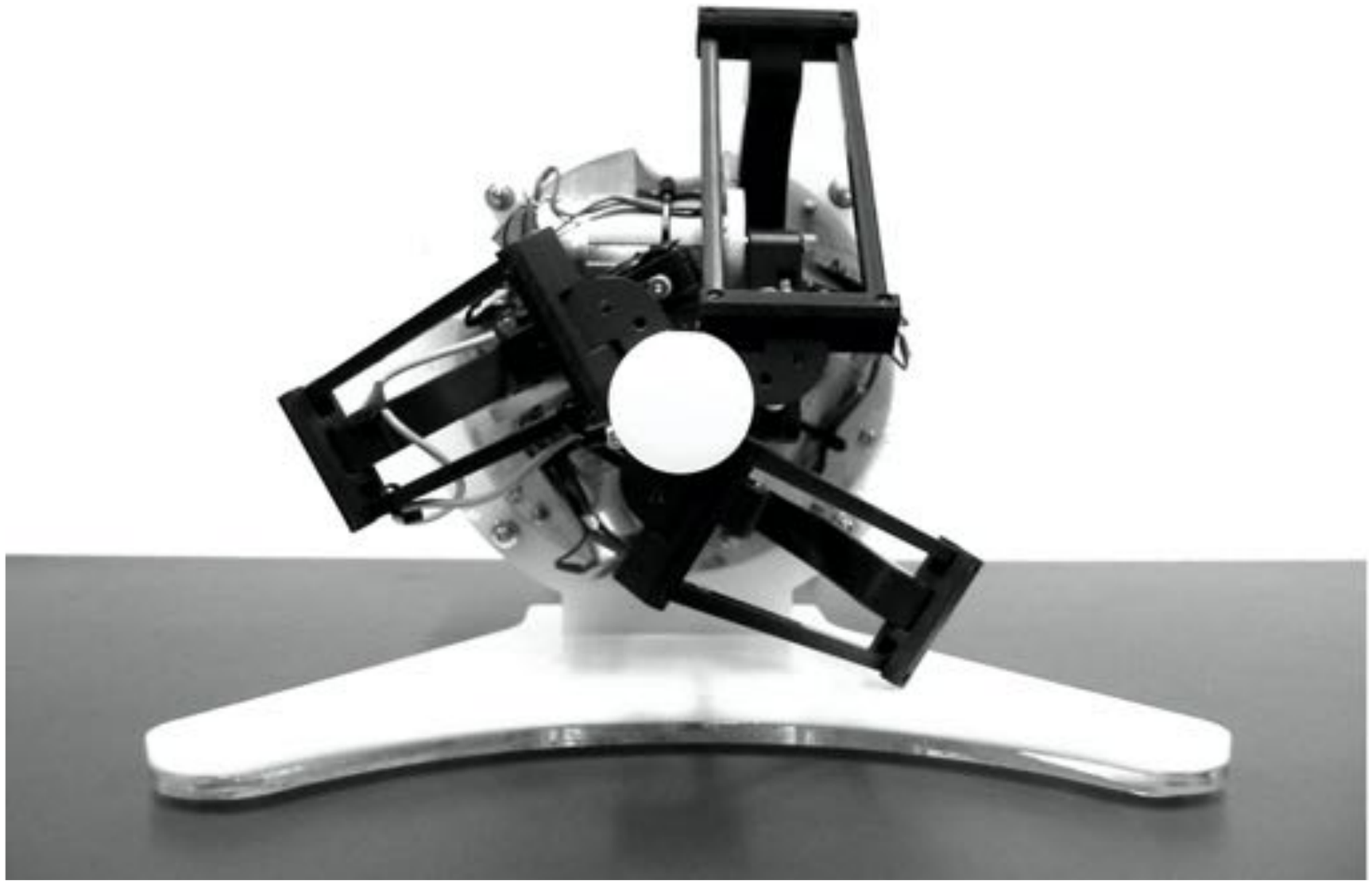
Product Creation

Designing Prototypes

Prototype
Force Dimension, Lunar Design

Product Creation

Designing Prototypes



Prototype
Force Dimension

Product Creation

Industrial Design

Falcon
Novint Technologies, Force Dimension

Product Creation

Industrial Design

Product Creation

Industrial Design

Product Creation

Industrial Design

Product Creation

First Production

Product Creation

Launching the Product

Patents

Protecting Ideas

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 690 651 A1

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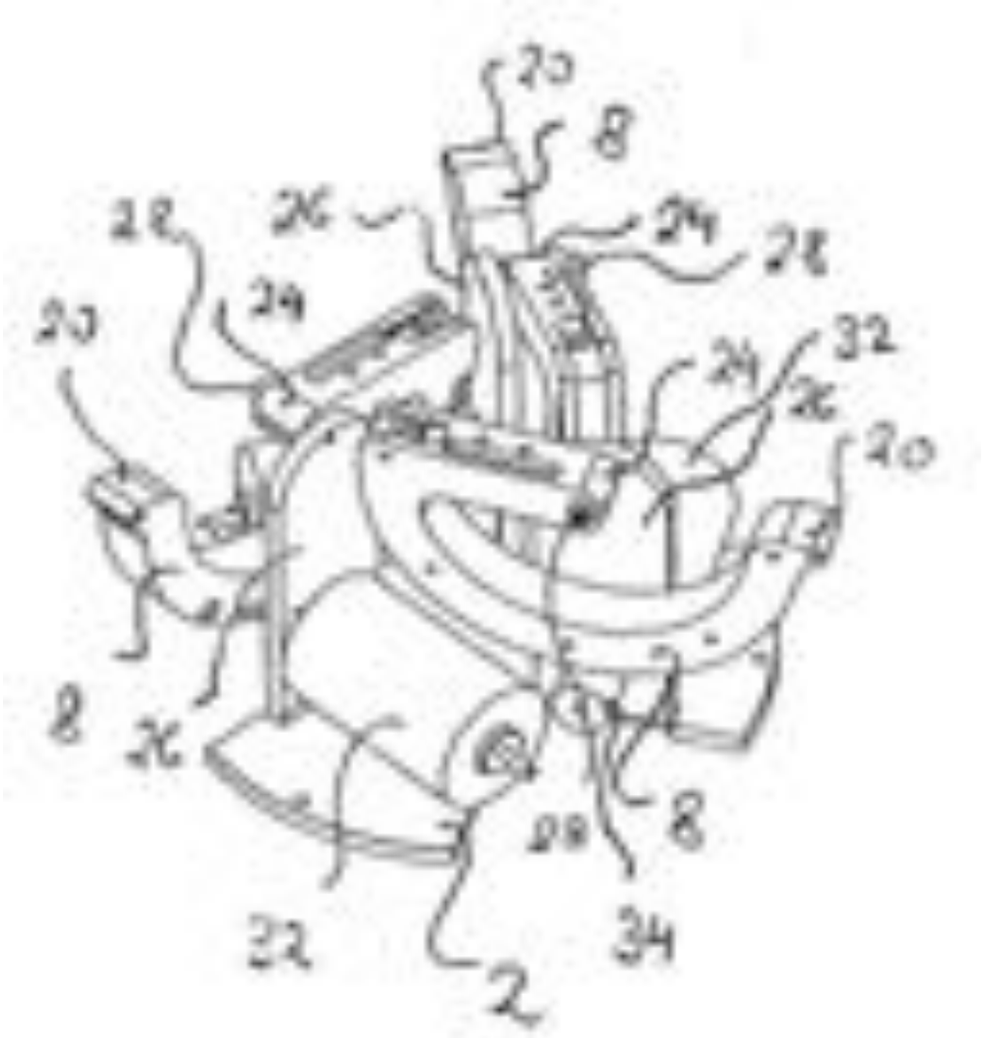
80538 München (DE)

(54) Kinematic chain with an arm comprising a curved portion and parallel kinematics transmission structure with such kinematic chains

(57) A kinematics chain (6) for a device for transmitting movements comprising a parallel kinematics transmission structure providing three degrees of freedom, the parallel kinematics transmission structure comprising a base member (2) and a movable member (4), the kinematics chain (6) comprising a first arm (8) adapted to be coupled to the base member (2) and comprising a curved portion (52).



Medical Applications

High-End Interfaces

Medical Applications

Building Partnerships

Sensei
Hansen Medical, Force Dimension

Quality Control

Certification and Validation

Haptics

The Sense of Touch









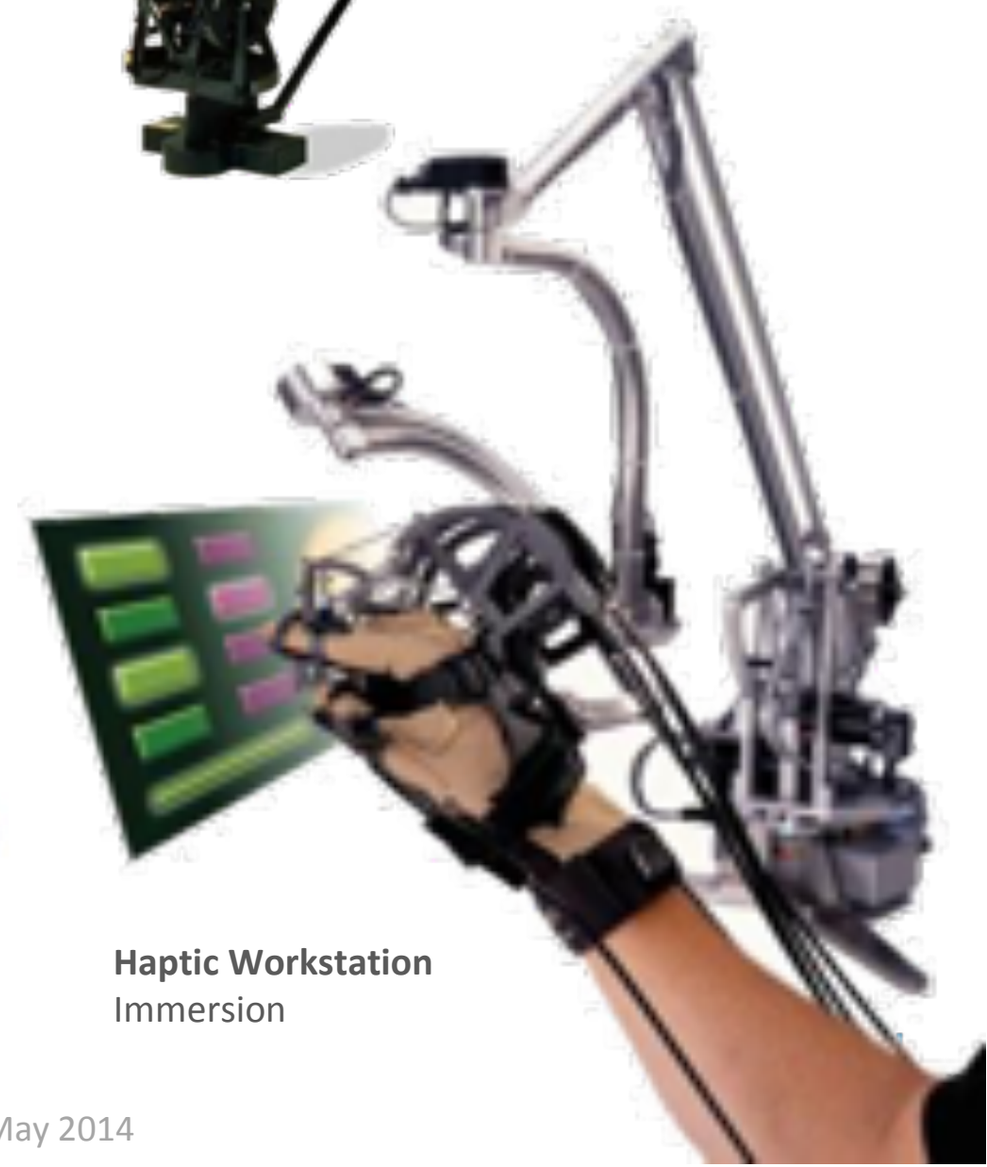

Haptic Devices

Market and Applications

Cybergrasp
Virtual Technologies

Phantom
MIT / Sensable Technologies

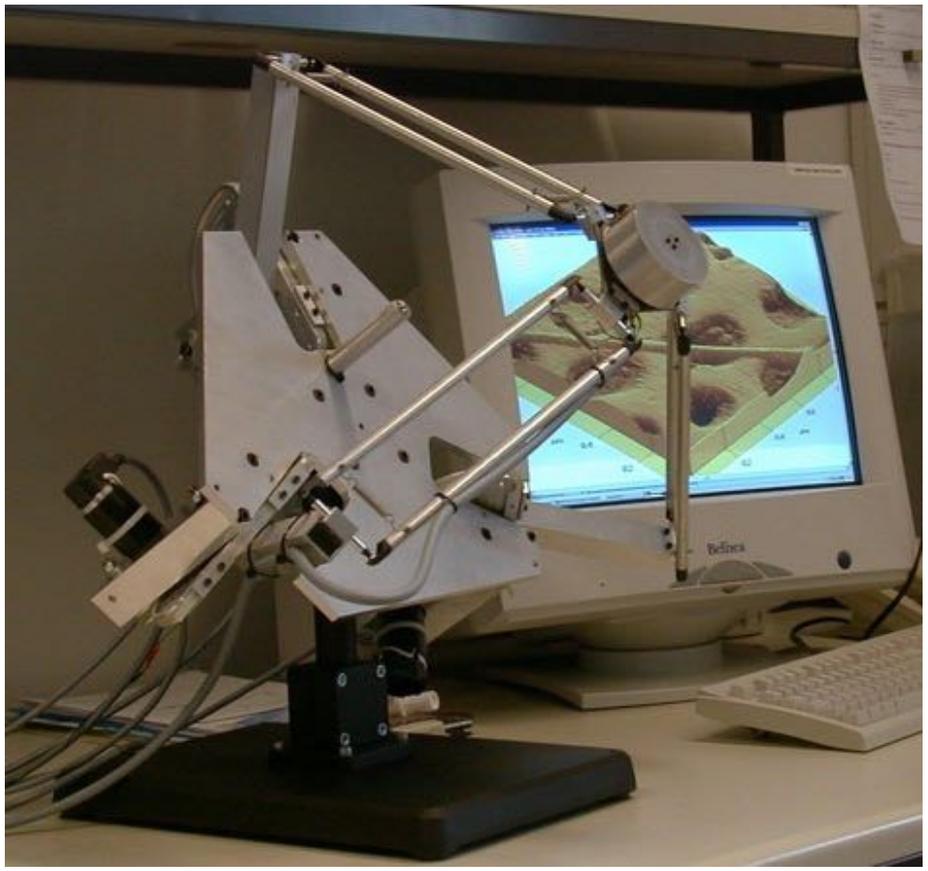
iDrive
Immersion Corporation



Haptic Workstation
Immersion

Le Syntaxeur

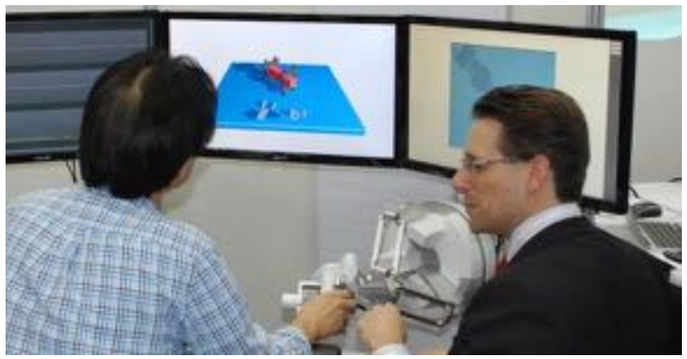
EPFL – Ecole Polytechnique Fédérale de Lausanne



Le Syntaxeur
EPFL, Switzerland

Creating a Company

Designing and Manufacturing Haptic Devices



Force Dimension
Switzerland