MEAM 520

Robot Hardware

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MEAM Department, SEAS, University of Pennsylvania

Lecture 15: November 6, 2012

Solutions to Homework 4 on reserve
in Engineering Library

MEAM 520 Midterm Details – Room is Chemistry 102 — robotics

Delete Junk Reply Reply All Forward Print To Do

From: Katherine Kuchenbecker
Subject: **MEAM 520 Midterm Details - Room is Chemistry 102**
Date: November 3, 2012 6:11:41 PM EDT
To: MEAM520-001-12C@LISTS.UPENN.EDU
Reply-To: Katherine Kuchenbecker

Dear class,

Our midterm will be this coming Thursday, November 8, during normal lecture time (12:00 p.m. to 1:20 p.m.)

Because our regular classroom is too small, we have reserved a different room for the exam. It is room 102 in the Chemistry Building. The Chemistry Building is located at 231 South 34th Street, which is at the corner of 34th and Spruce, very close to the main SEAS complex.

The exam will cover chapters 1 through 4 in our textbook, including all the concepts in homework assignments 1 through 4 and project 1. If you want to know if a certain topic is on the midterm, please post a question on Piazza.

You will be allowed to bring a calculator and two single-sided pages of handwritten and/or typed notes into the exam. You will not be able to look at your textbook.

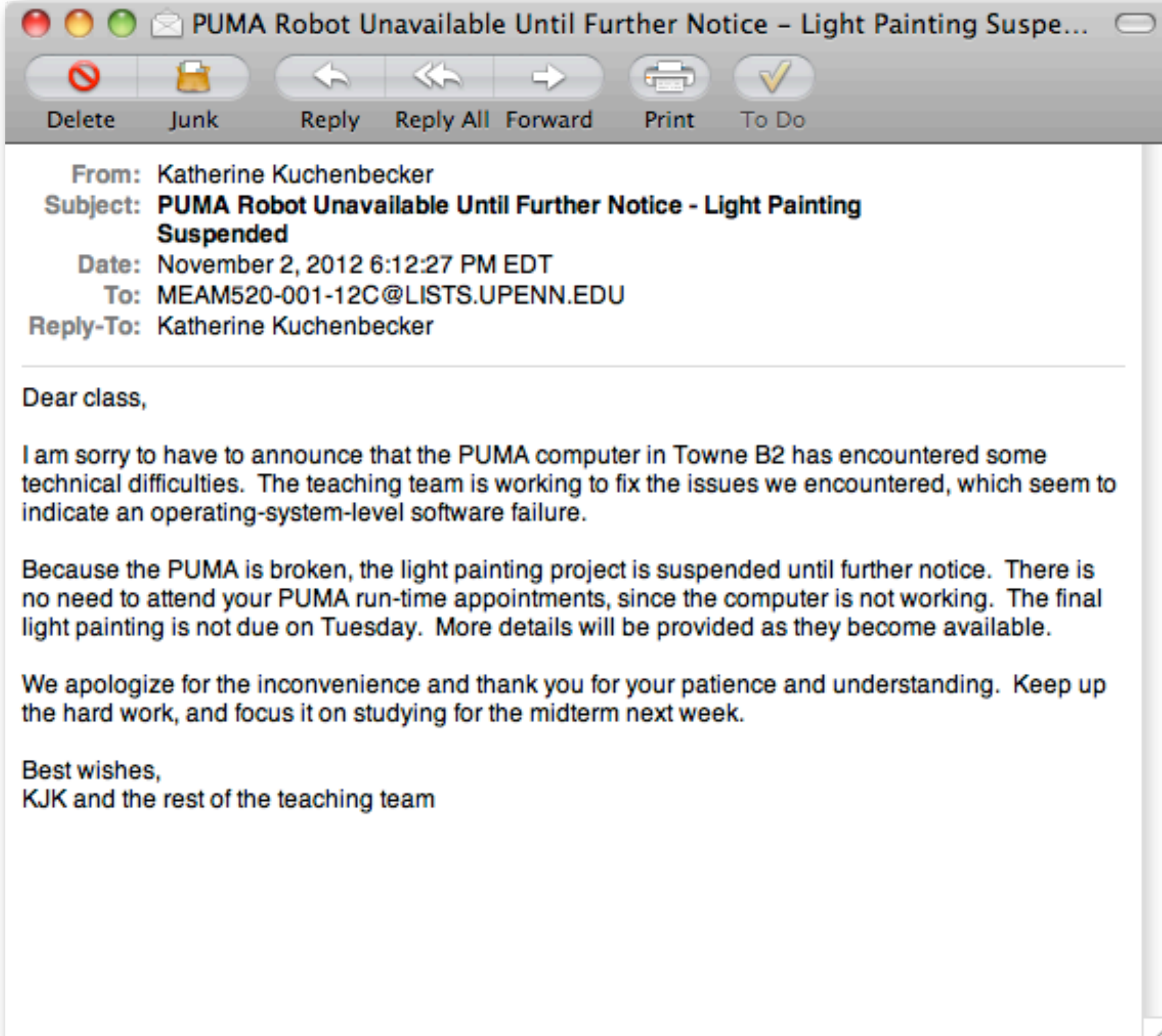
The TAs may be able to offer a review session early in the week. More information about that will be available soon.

I wish you all the best on this exam.

Best wishes,
KJK

Midterm on Thursday in Chemistry 102

Review Session Wednesday Evening?



From: Katherine Kuchenbecker
Subject: **PUMA Robot Unavailable Until Further Notice - Light Painting Suspended**
Date: November 2, 2012 6:12:27 PM EDT
To: MEAM520-001-12C@LISTS.UPENN.EDU
Reply-To: Katherine Kuchenbecker

Dear class,

I am sorry to have to announce that the PUMA computer in Towne B2 has encountered some technical difficulties. The teaching team is working to fix the issues we encountered, which seem to indicate an operating-system-level software failure.

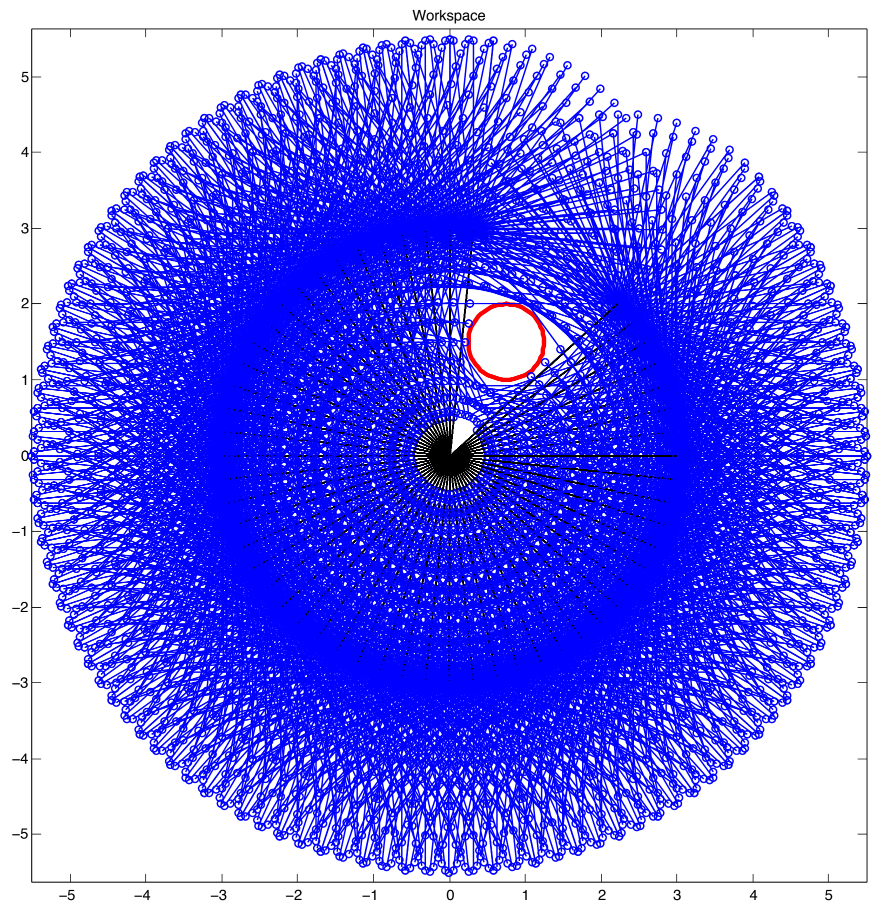
Because the PUMA is broken, the light painting project is suspended until further notice. There is no need to attend your PUMA run-time appointments, since the computer is not working. The final light painting is not due on Tuesday. More details will be provided as they become available.

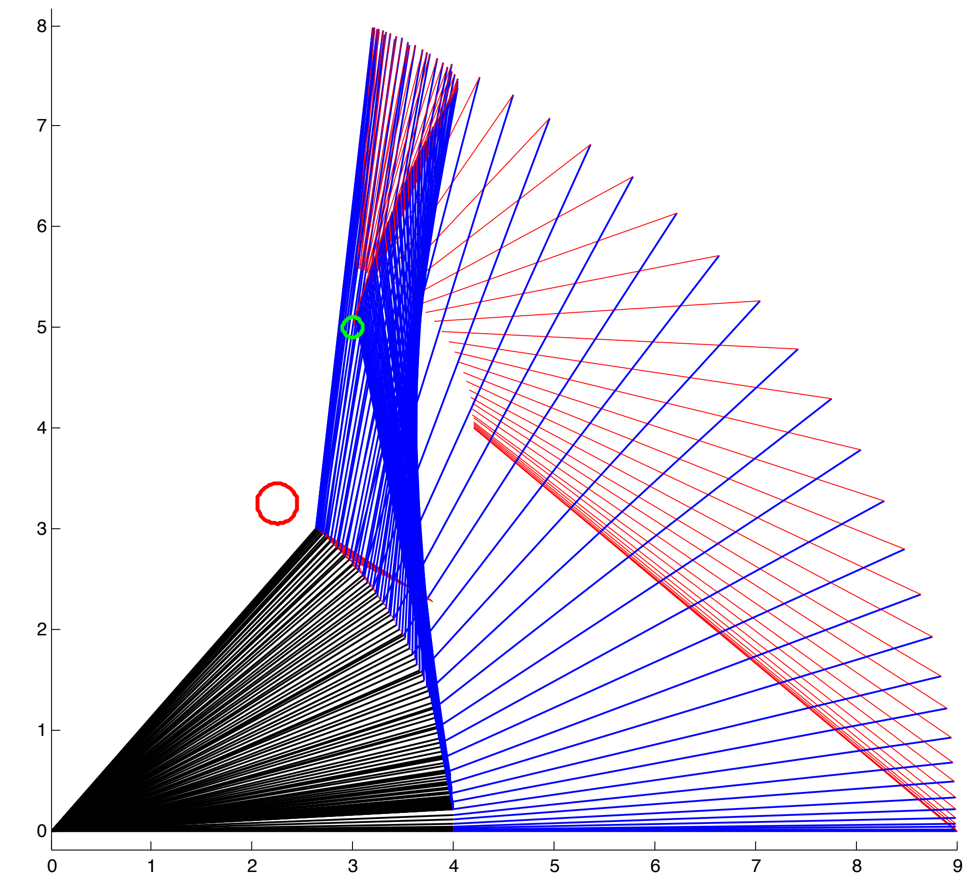
We apologize for the inconvenience and thank you for your patience and understanding. Keep up the hard work, and focus it on studying for the midterm next week.

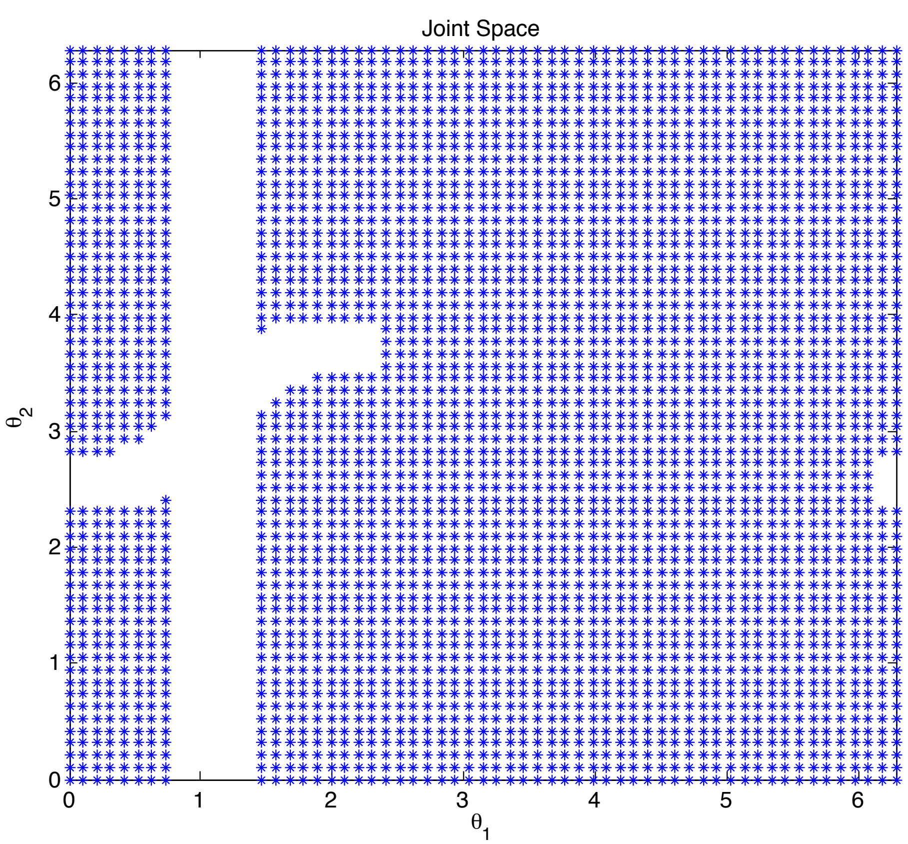
Best wishes,
KJK and the rest of the teaching team

PUMA Computer Update

Last Time



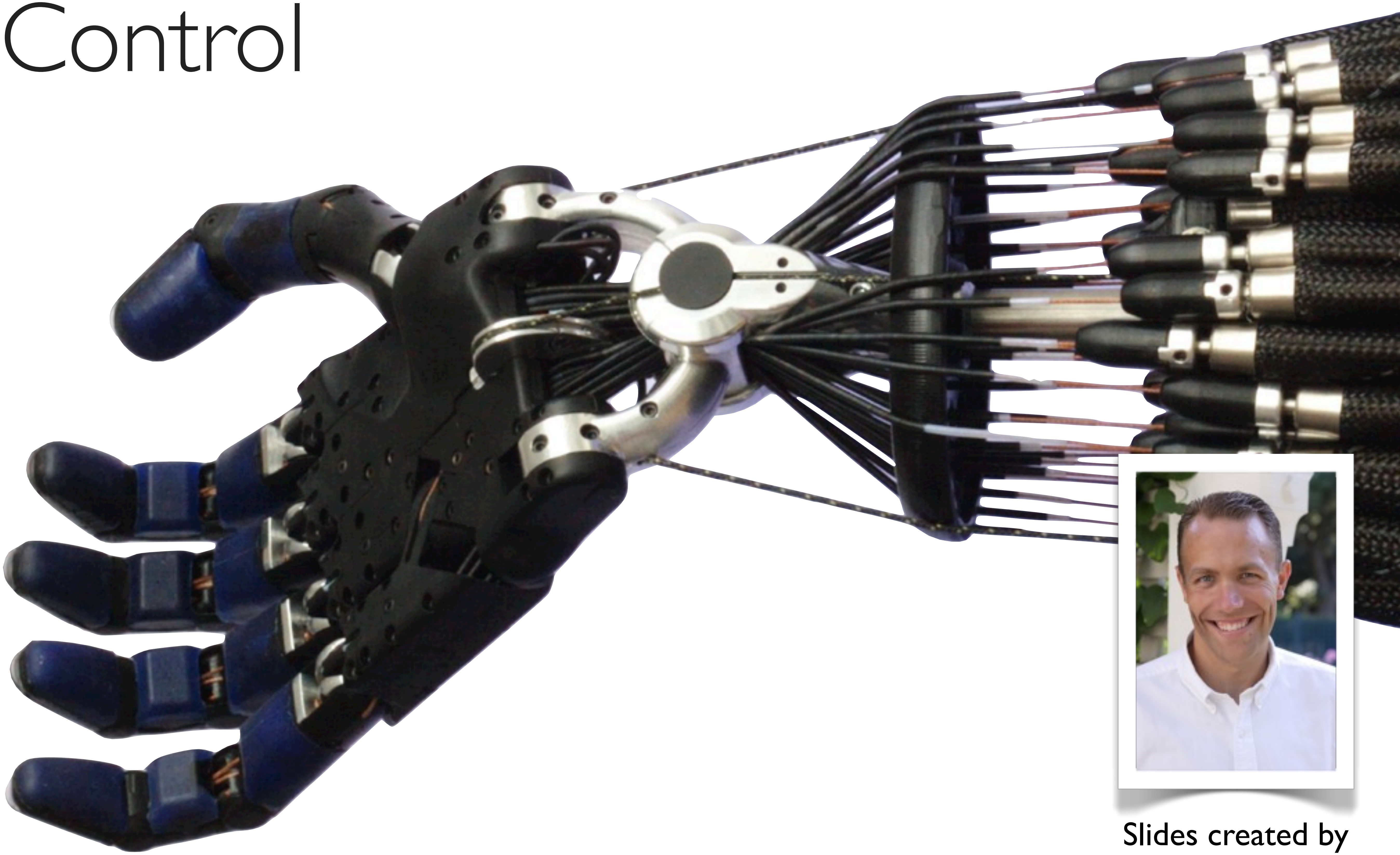




$$\vec{\tau} = J_v^T \vec{F}$$

We'll do the rest of Chapter 5 later.

Manipulator Hardware and Control



Slides created by Jonathan Fiene

Project 2

A Biological Inspiration

Mechanical Structure

Bones	Frame / Links
Joints	Joints

Actuators

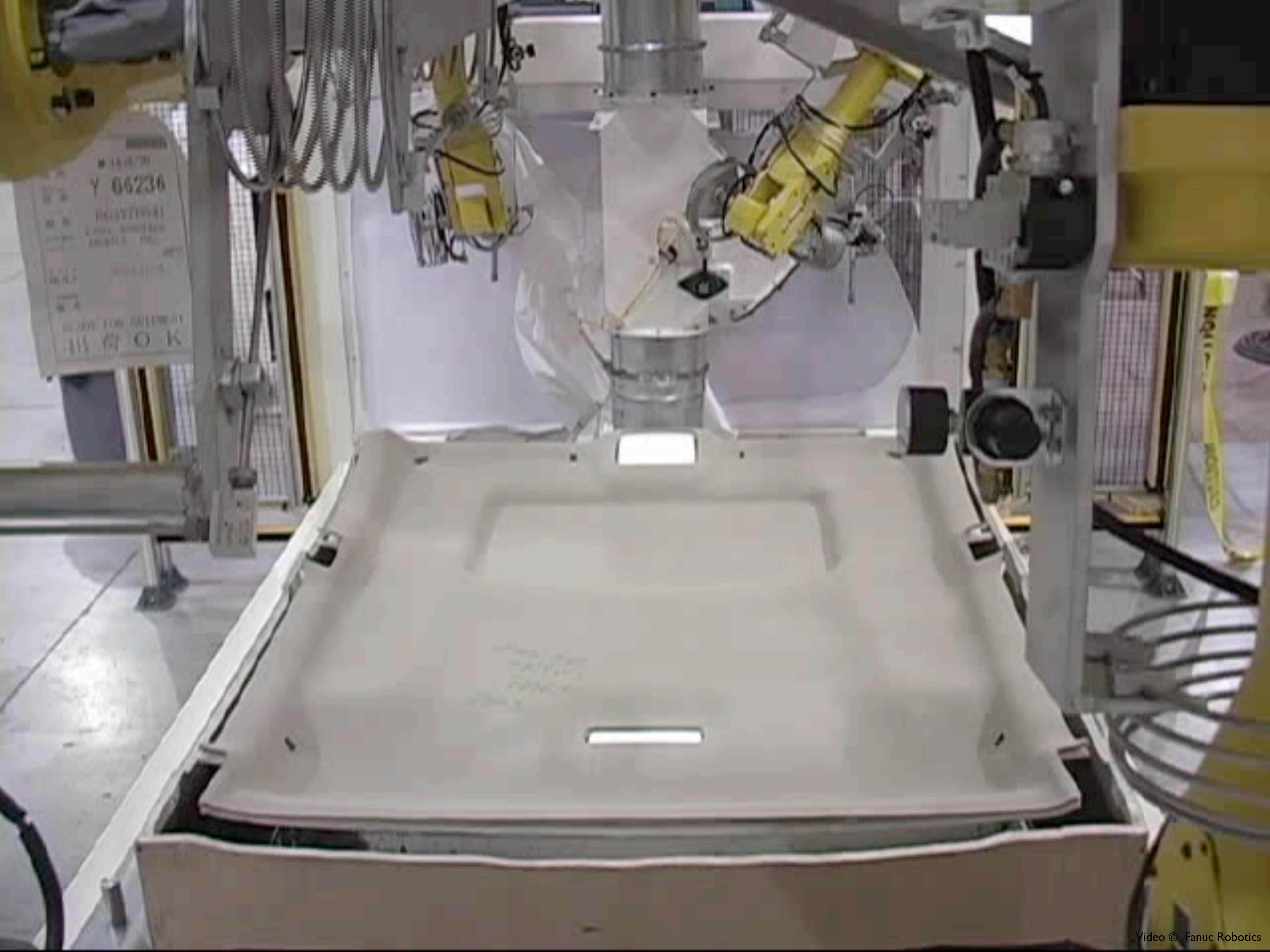
Muscles	Electric Motors
	Hydraulics
	Pneumatics
	SMA, etc.

Sensors

Kinesthetic	Encoders
Tactile	Load Cells
Vision	Vision
Vestibular	Accelerometers

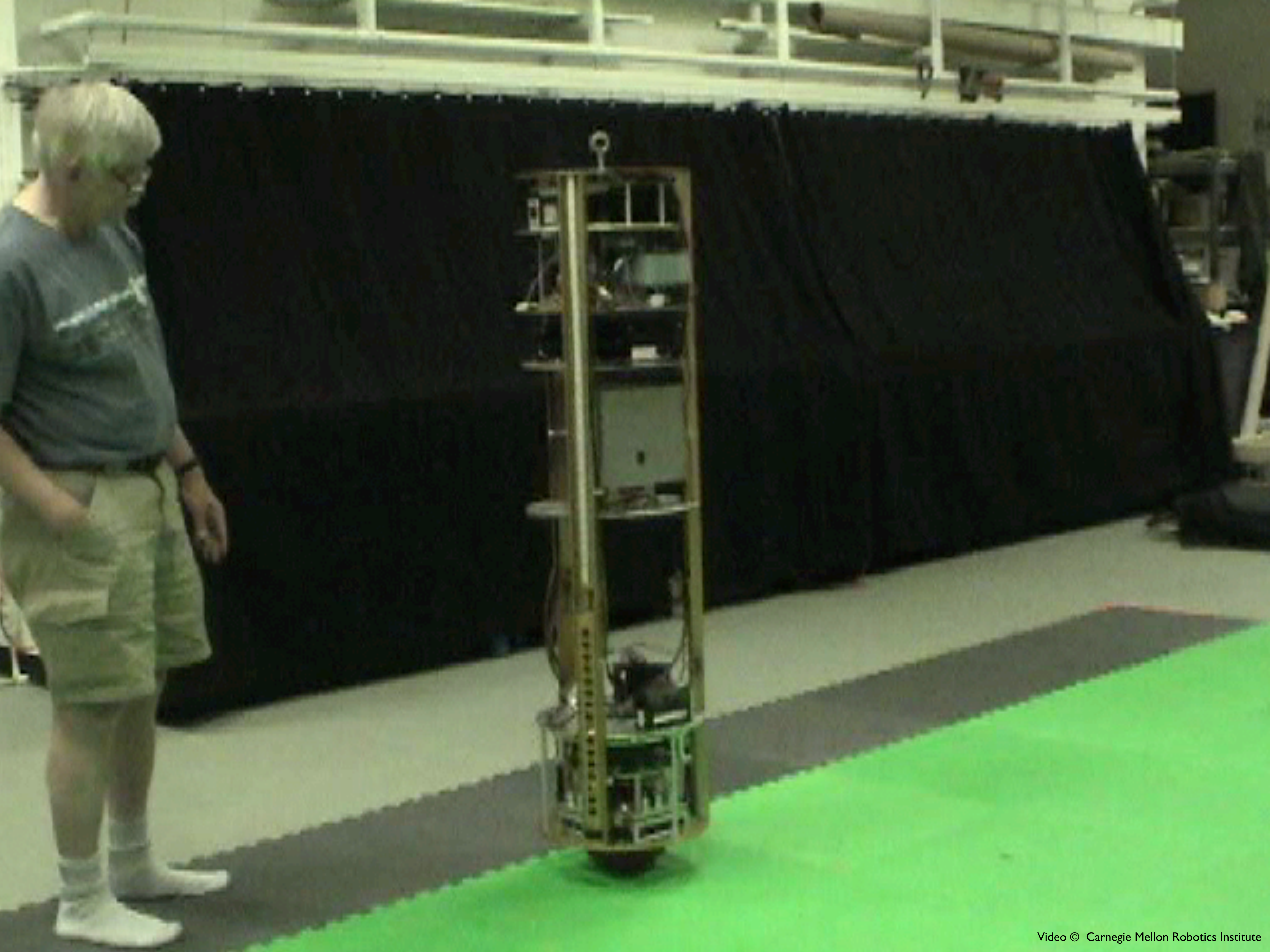
Controller

Brain	Computer
Spinal Cord Reflex	Local feedback

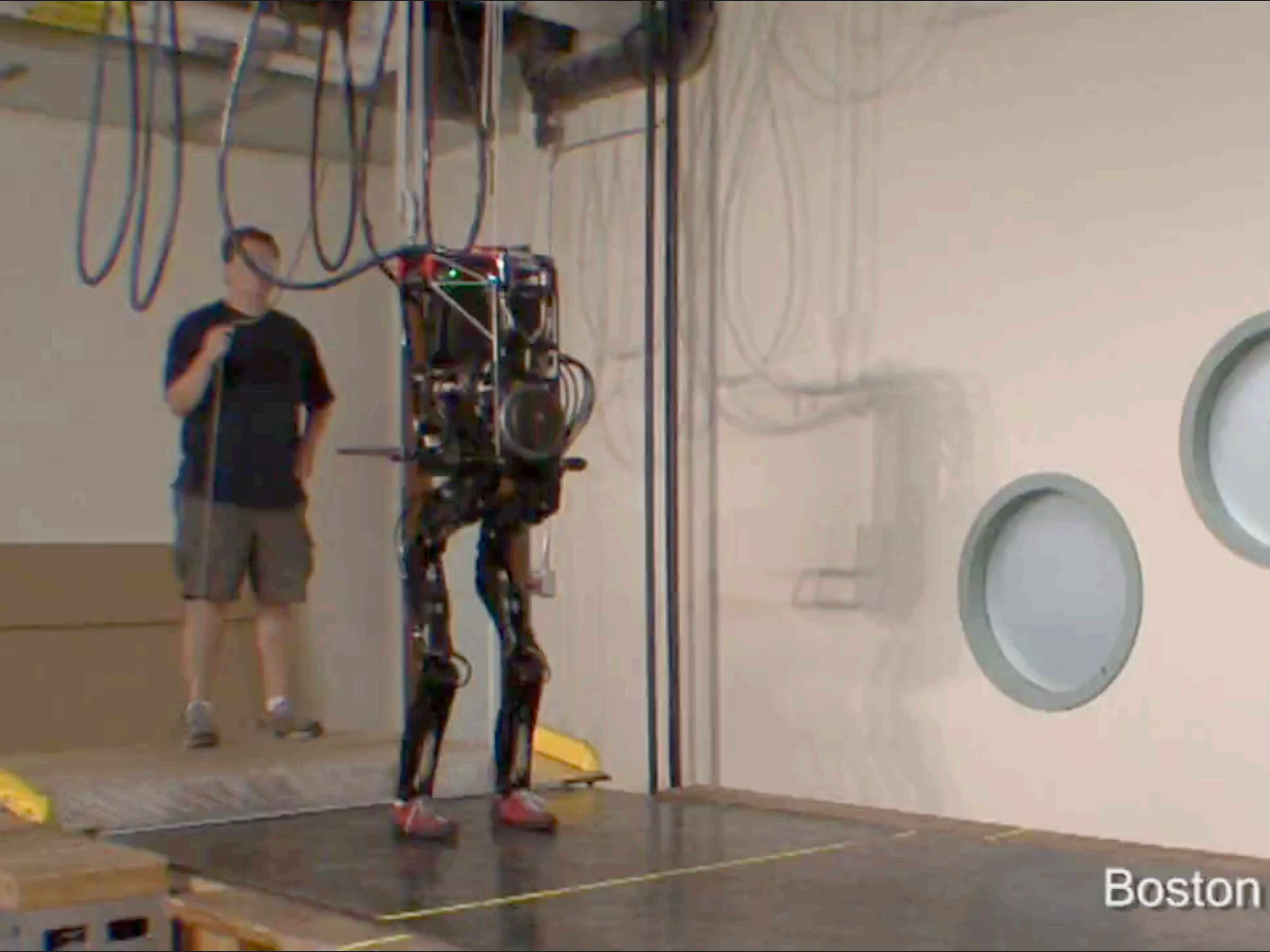


Video ©. Fanuc Robotics

Video © Fanuc Robotics

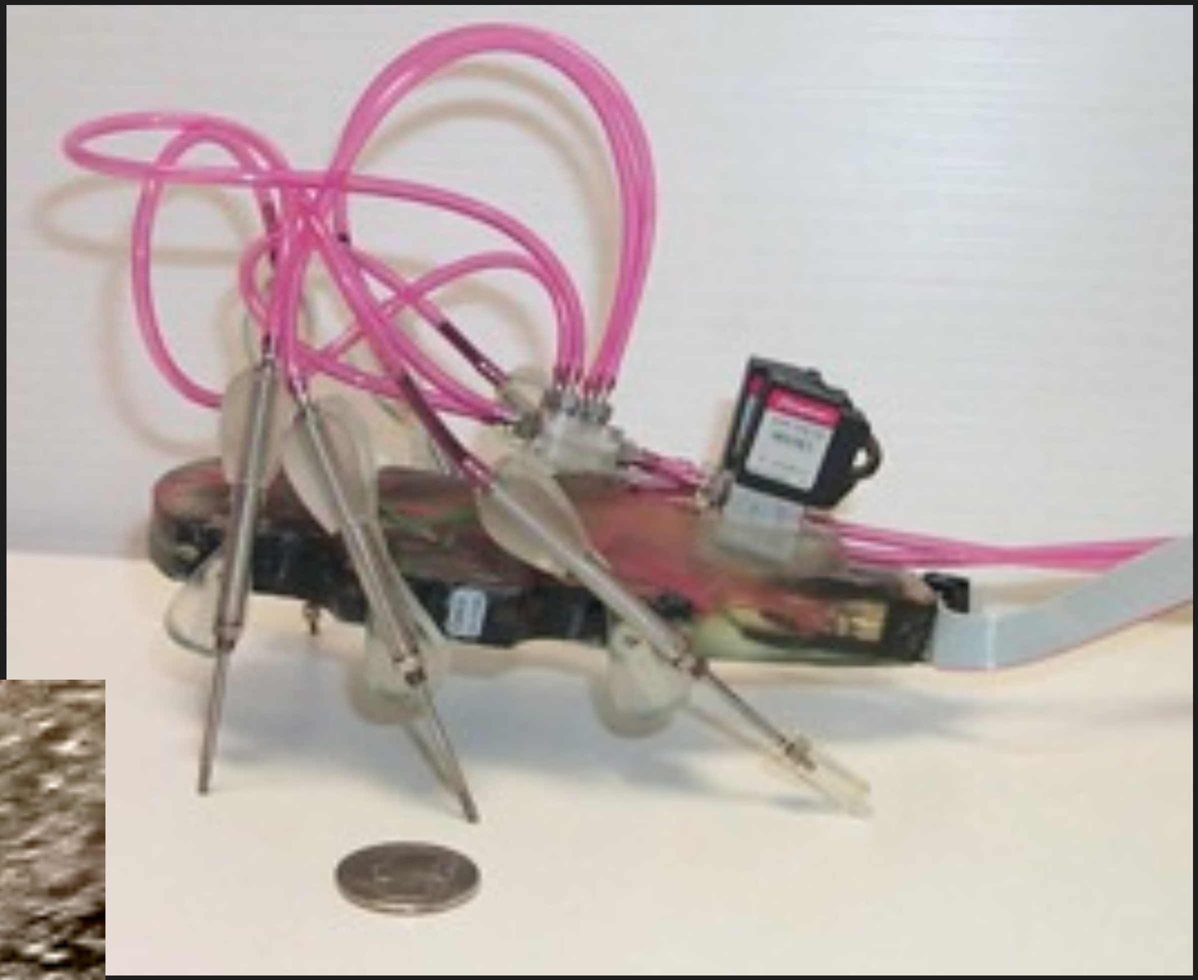



Boston Dynamics

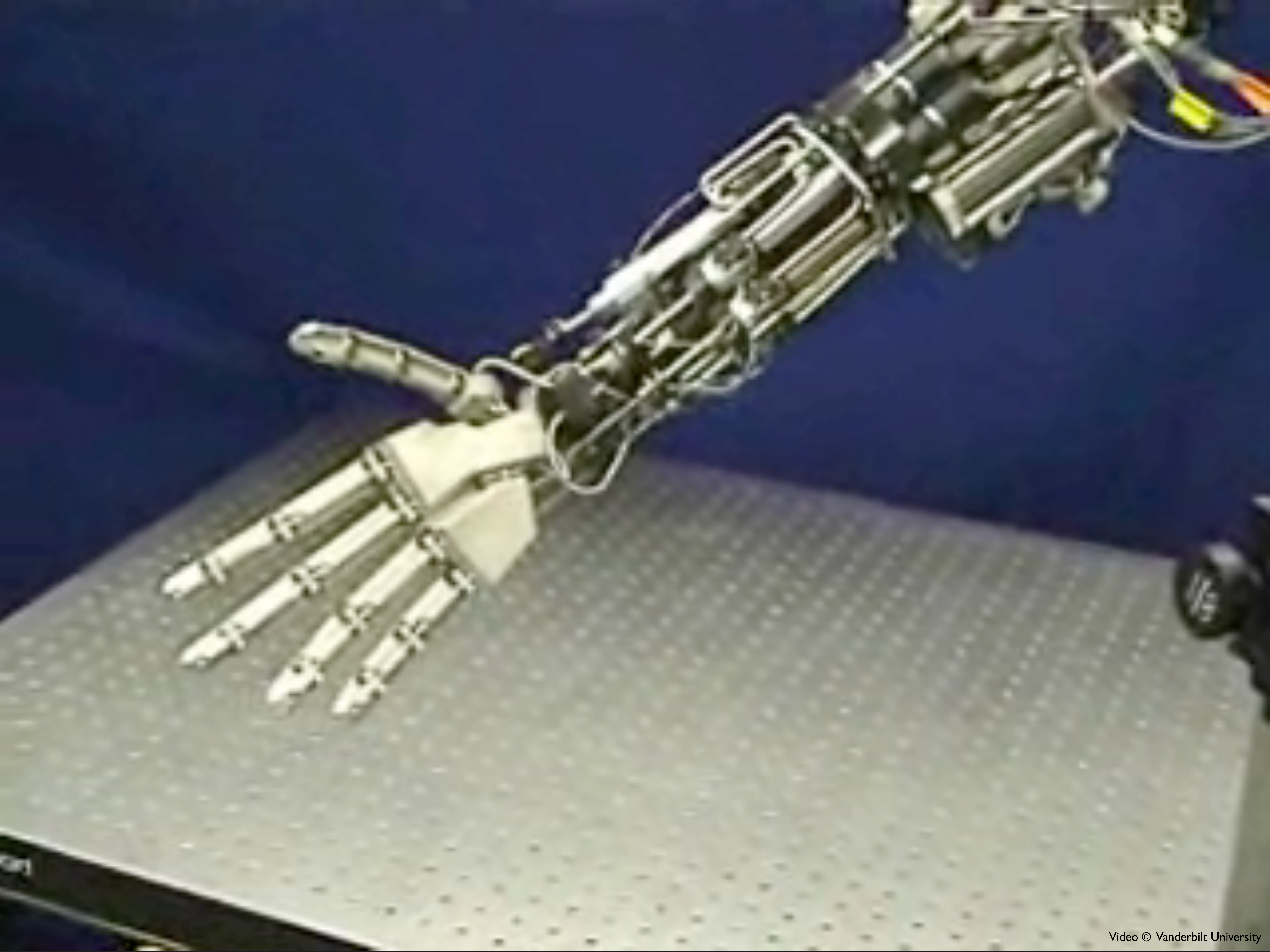

Boston

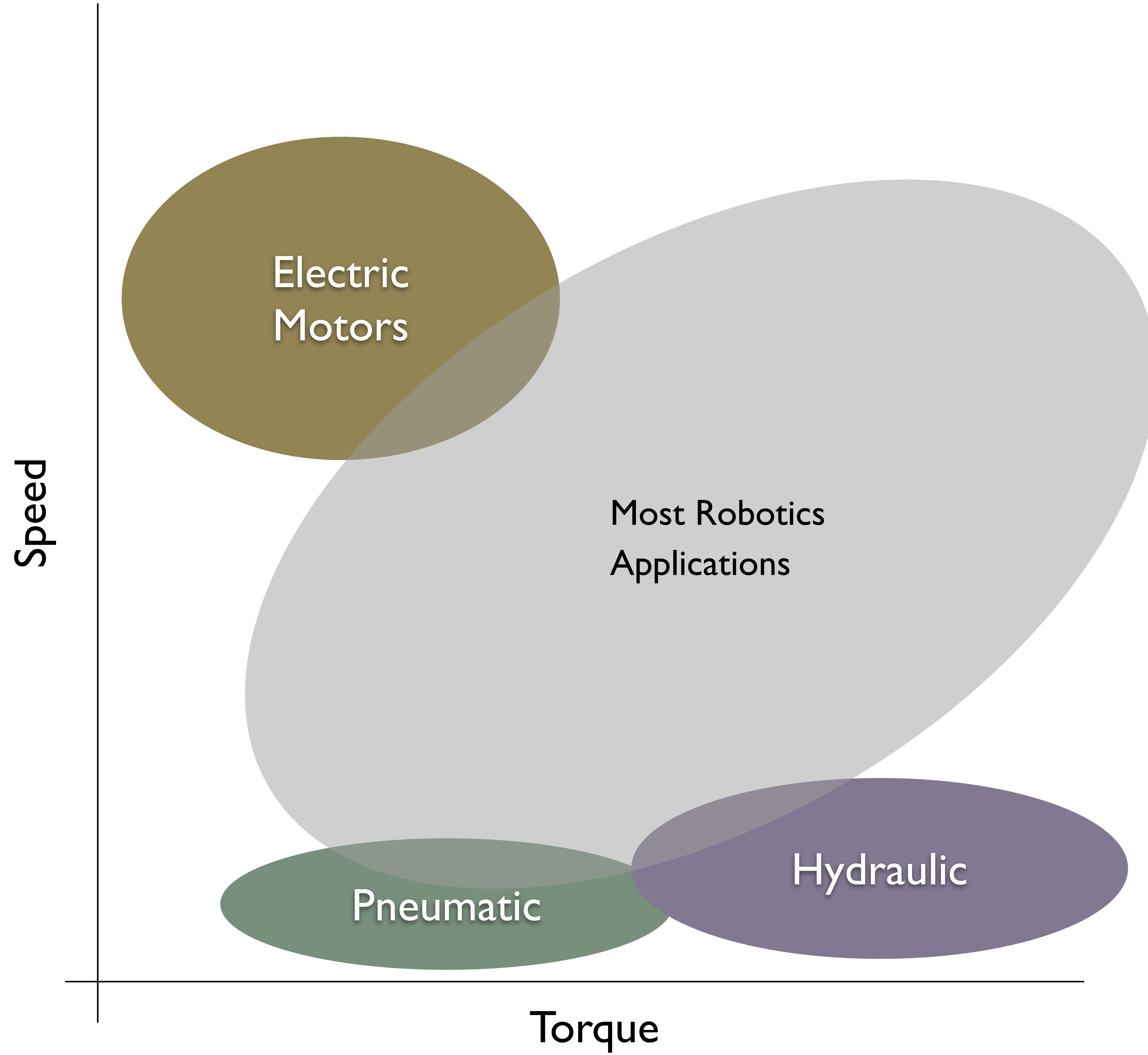

RHex

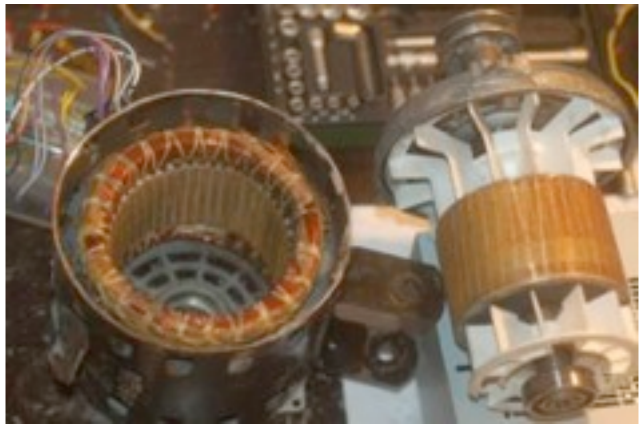
Actuators



Video © Stanford University




Electric Motors
Most Robotics Applications
Pneumatic
Hydraulic
Speed
Torque

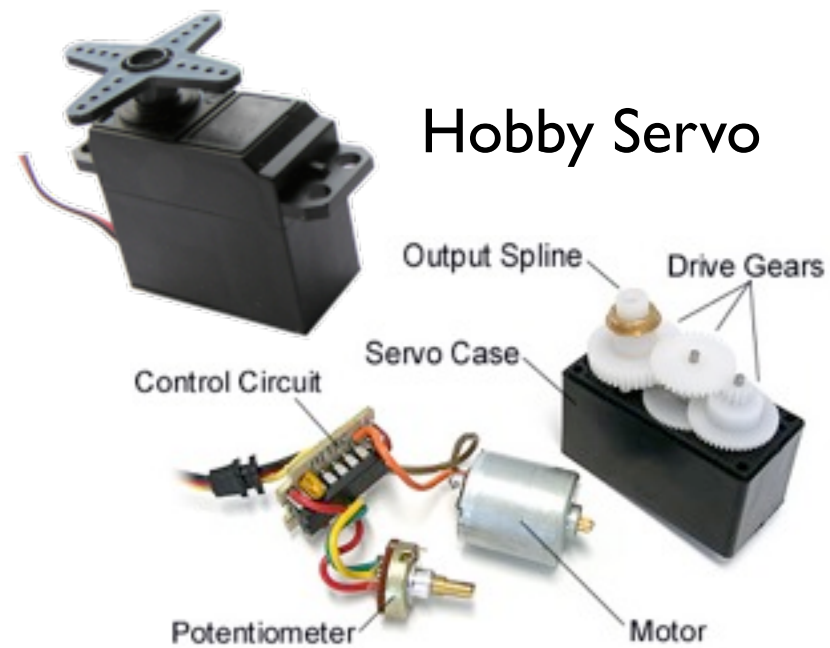


AC

Magnetic Rotor
Coil Stator
Output speed is a sub-multiple of voltage supply frequency

DC Brushed

Coil Rotor
Magnetic Stator
Brushes carry current to the rotor

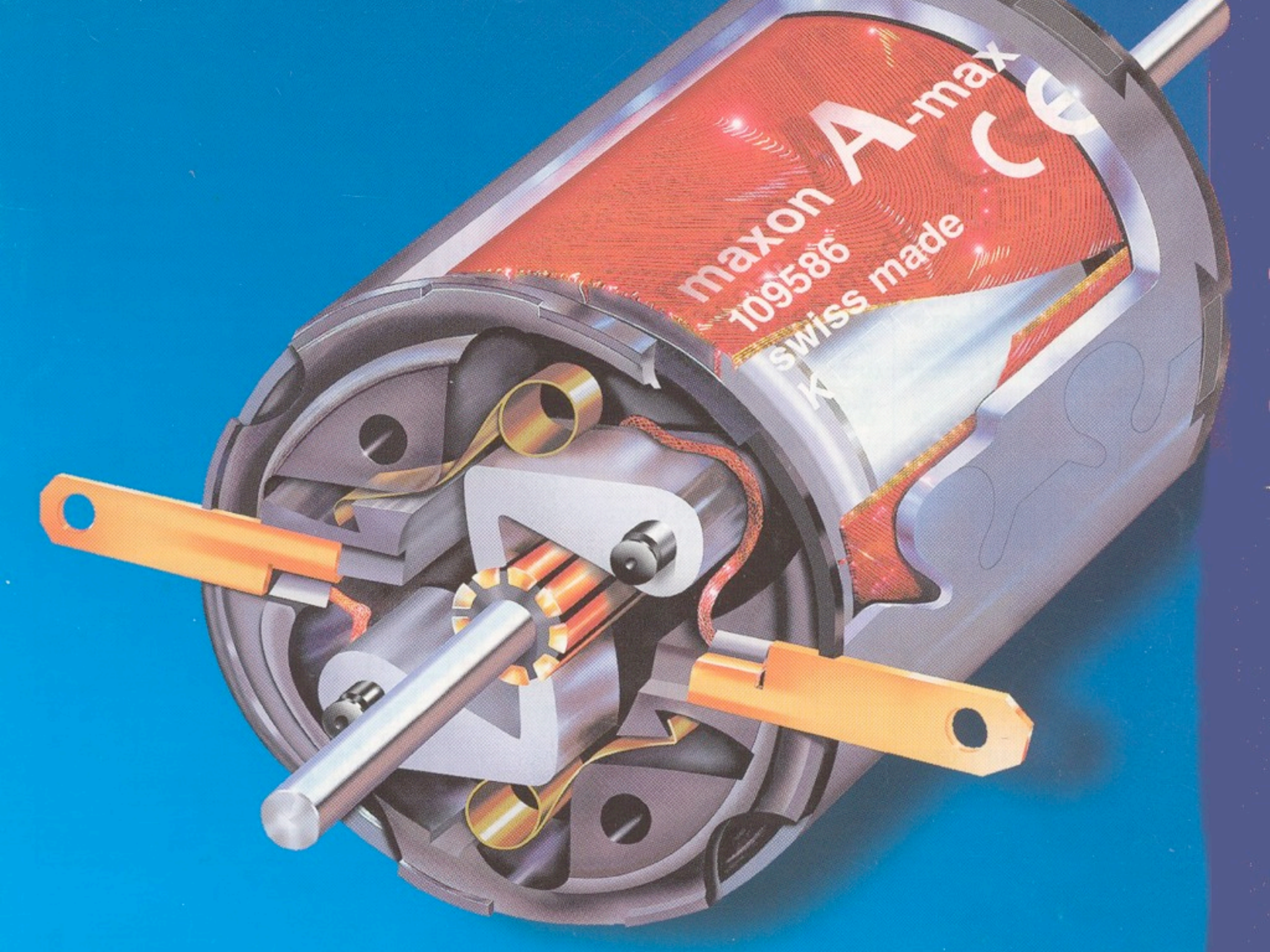


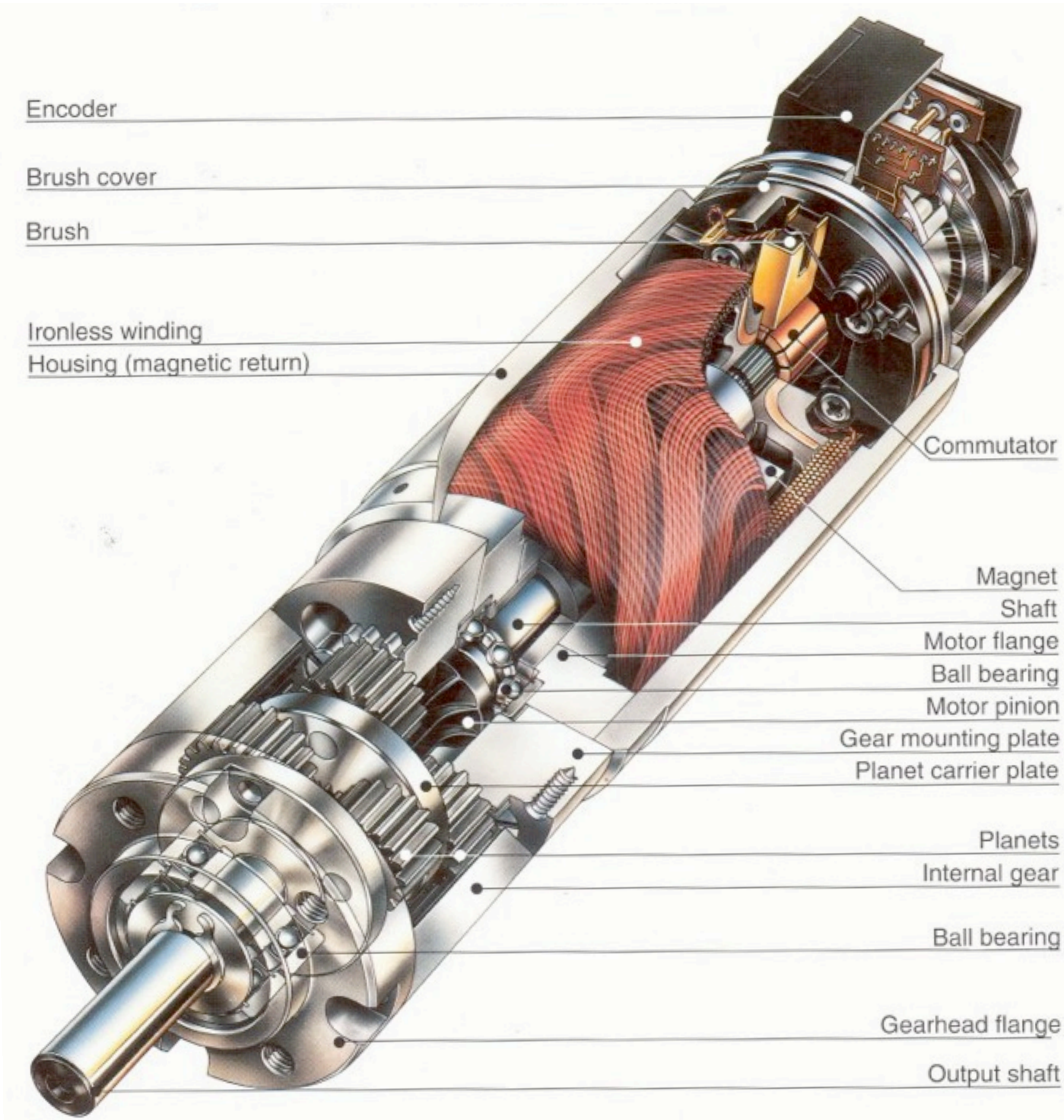
DC Brushless

Magnetic Rotor
Coil Stator
Similar in construction to AC, but electrically commutated
Requires a position sensor (commonly built in)

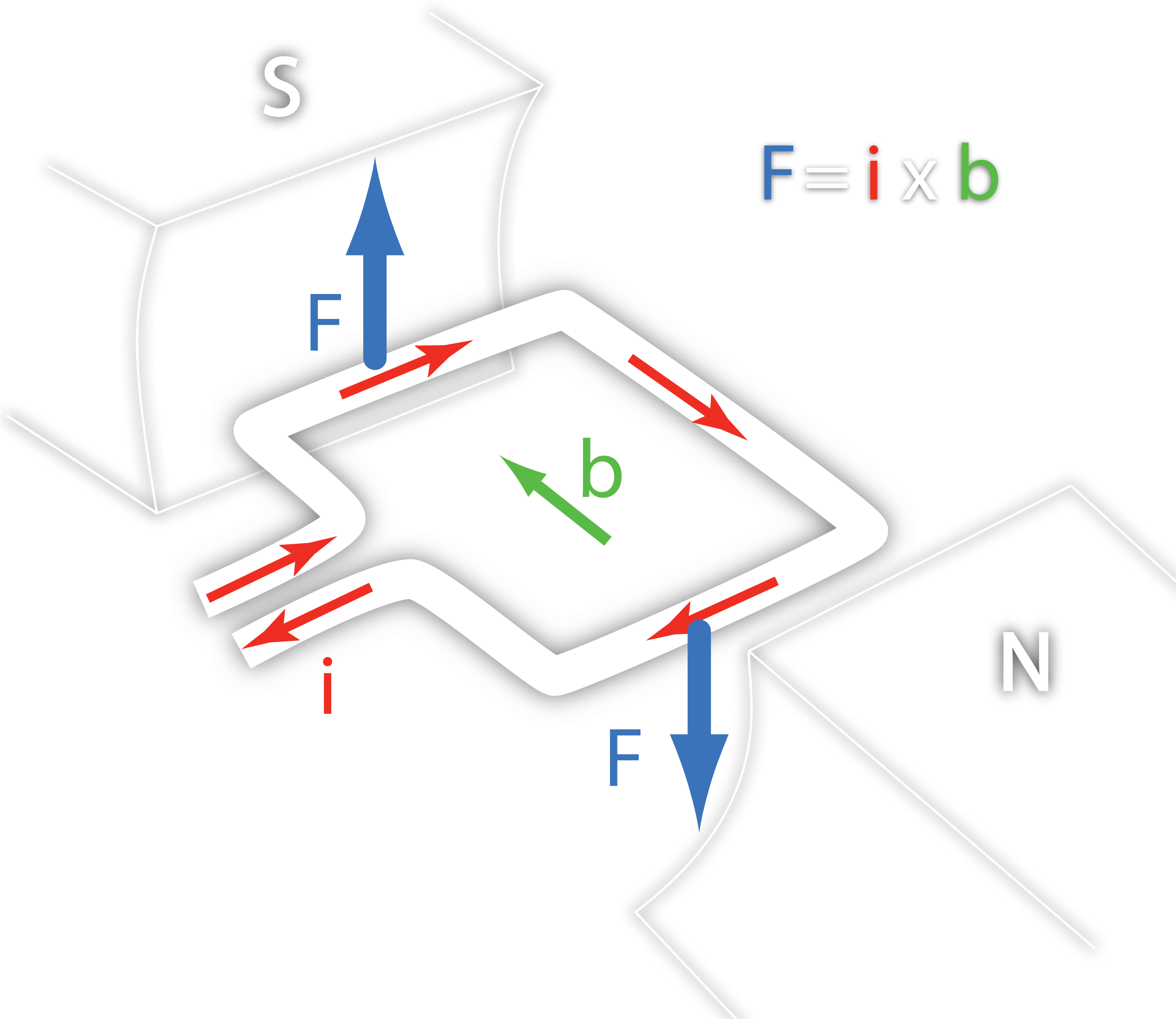
Stepper

Toothed Magnetic Rotor
Multi-Coil Stator
Capable of open-loop positioning
Requires a controller

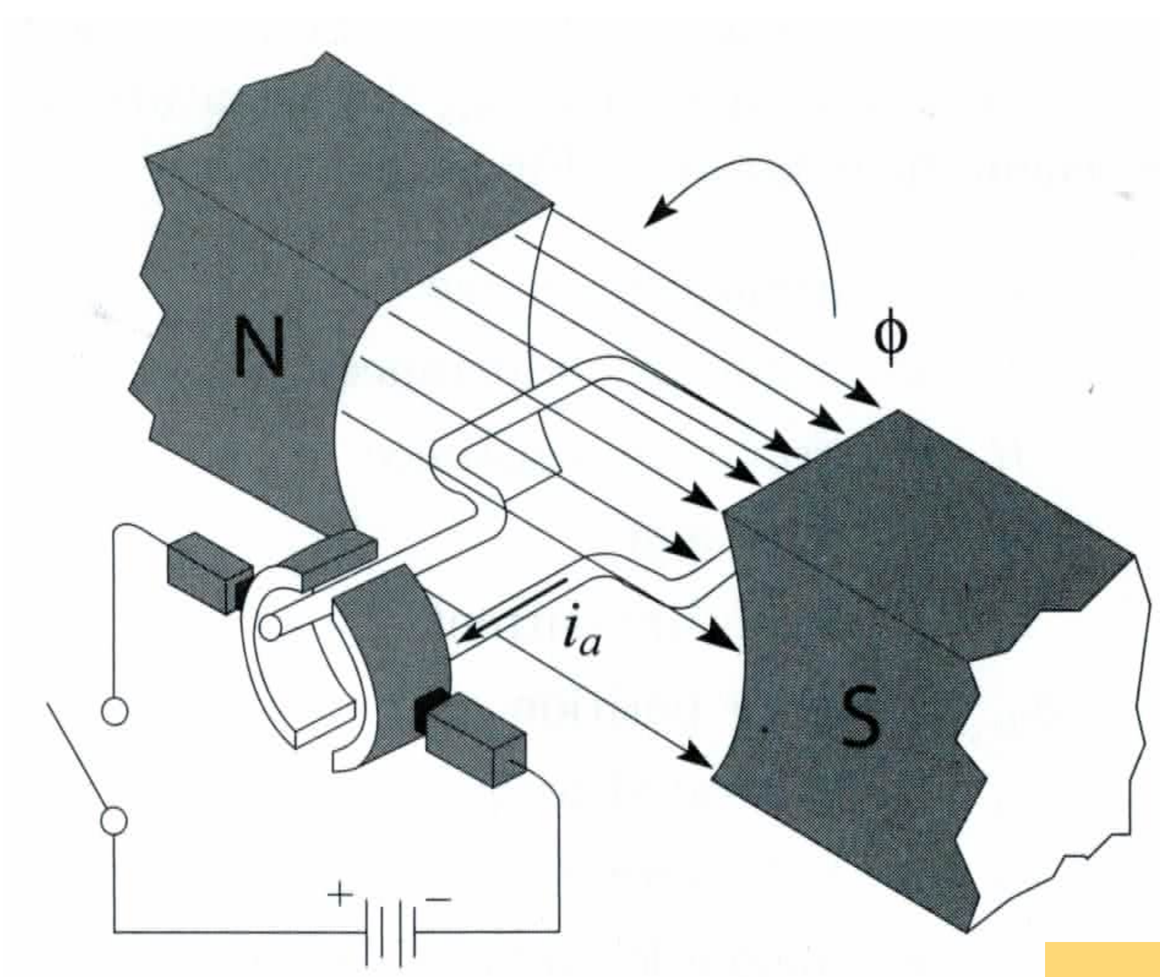

maxon A-max
109586
swiss made
CE


Encoder
Brush cover
Brush
Ironless winding
Housing (magnetic return)
Commutator
Magnet
Shaft
Motor flange
Ball bearing
Motor pinion
Gear mounting plate
Planet carrier plate
Planets
Internal gear
Ball bearing
Gearhead flange
Output shaft

DC Brushed Motors



SHV Section 6.1

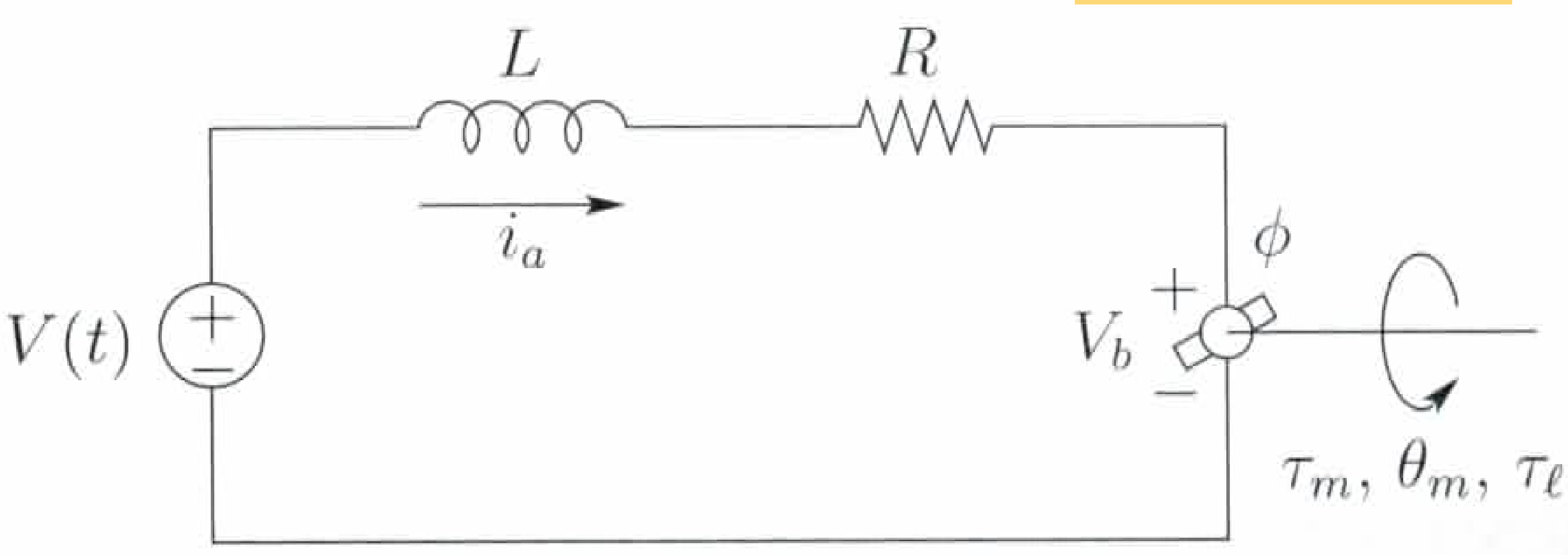


$$\tau_m = K_1 \, \phi \, i_a = k_t \, i_a$$

- τ_m: generated torque (N•m)
- K_1: physical constant
- ϕ: magnetic flux (webers)
- i_a: armature current (A)
- k_t: torque constant (N•m/A)
- i_a: armature current (A)

$$k_t = k_v$$

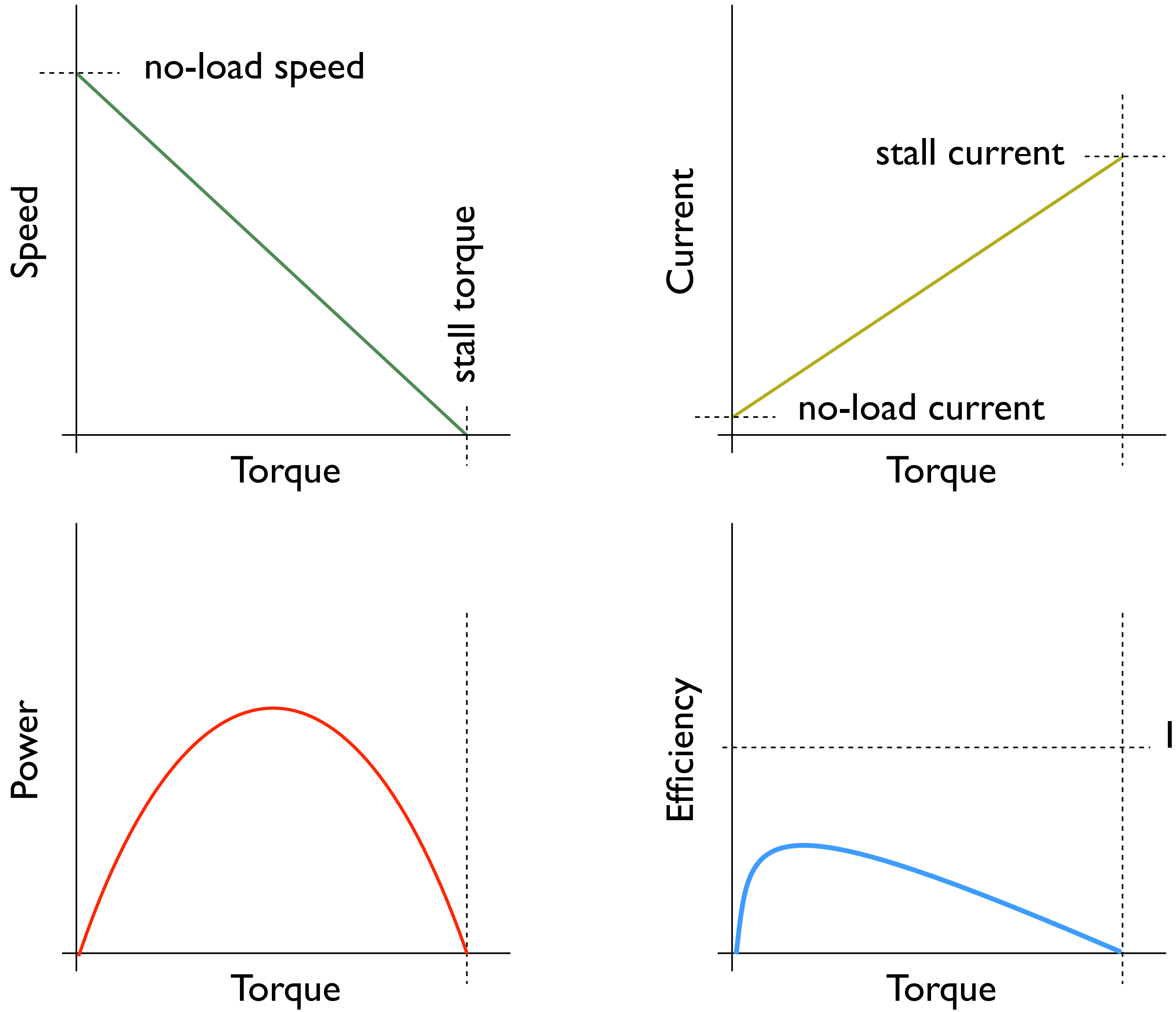
if using meters, kilograms and seconds



$$V_b = K_2 \, \phi \, \omega_m = k_v \, \omega_m$$

- V_b: back emf (V)
- K_2: physical constant
- ϕ: magnetic flux (webers)
- ω_m: motor velocity (rad/s)
- k_v: back-emf constant (V•s)
- ω_m: motor velocity (rad/s)

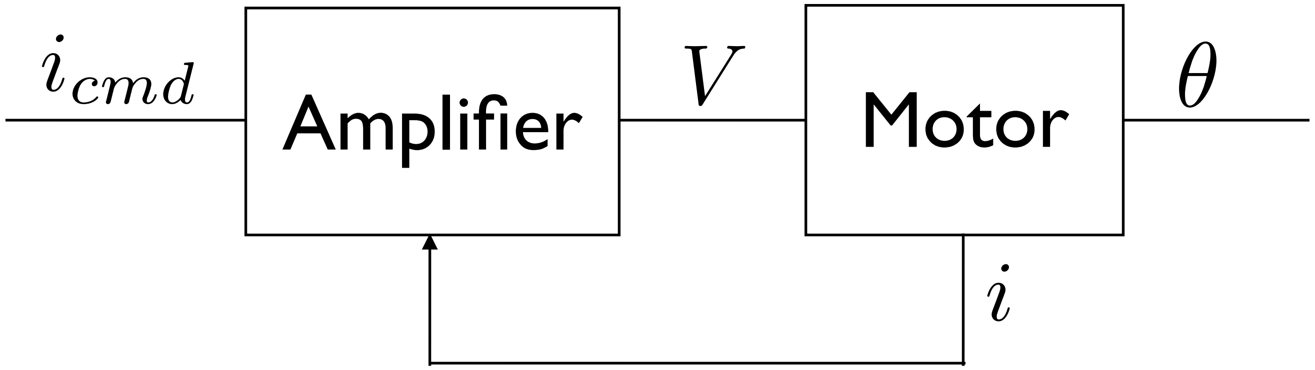
DC Brushed Motors - Governing Relationships



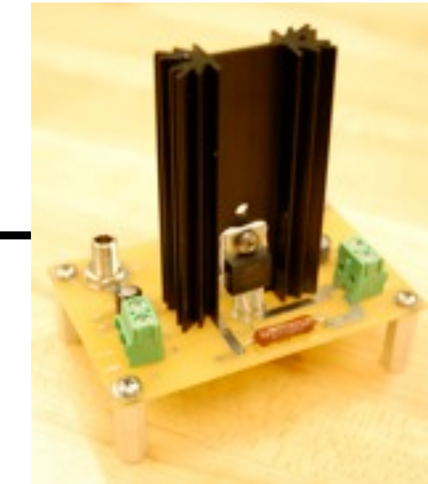
Motor

The best brushed DC motors are made by Maxon. They are rather expensive, but they work quite well.

- Smooth torque output, independent of motor angle. In other words, very low cogging and torque ripple.
- Low friction, both at low and high speeds, due to high quality bearings and low eddy currents.
- Relatively high stall torque, which is the torque the motor can deliver when it is not rotating.
- Larger motors create higher torques, but they also have higher inertia and higher friction.

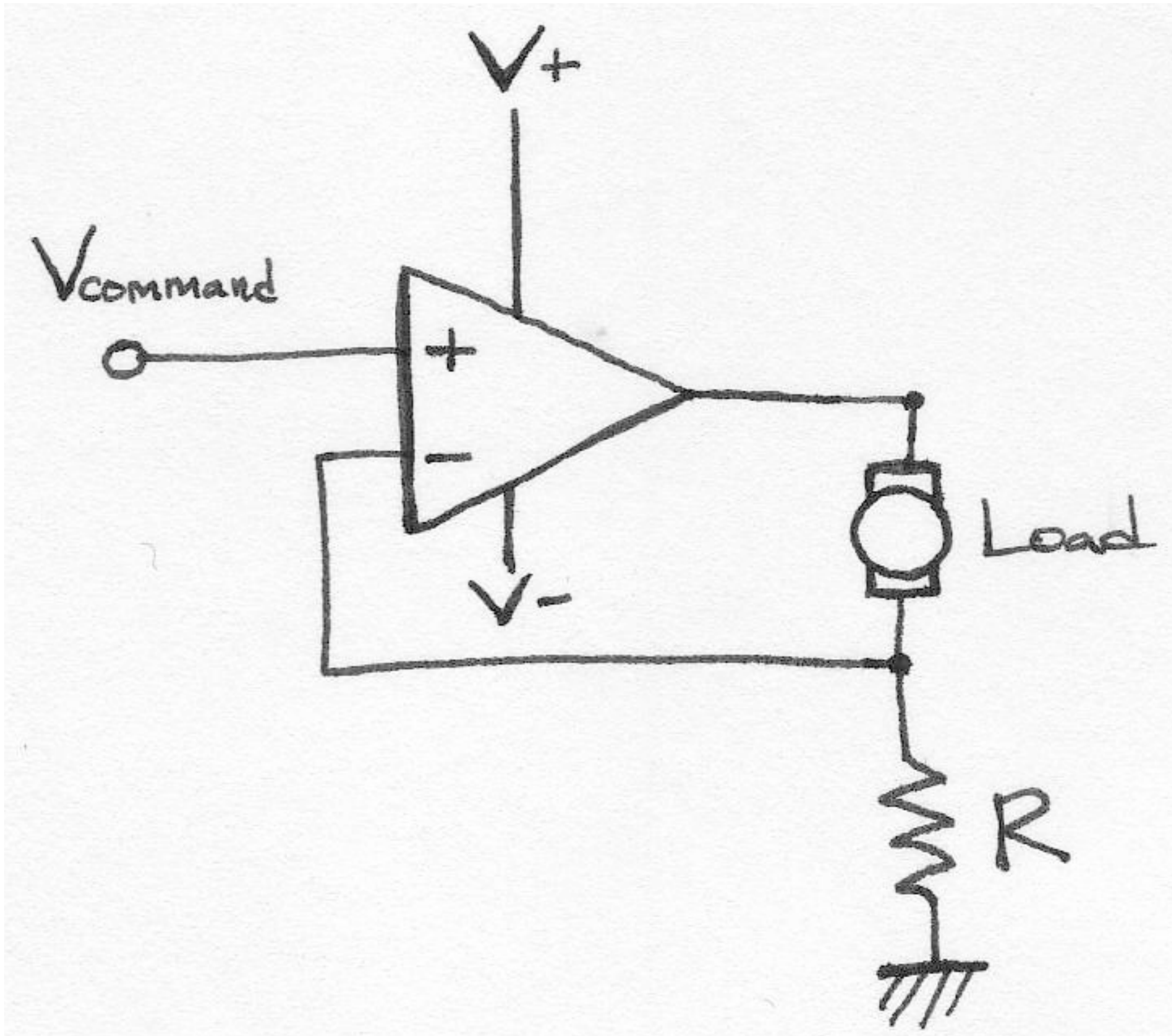

i_{cmd}
Amplifier
V
Motor
θ
i

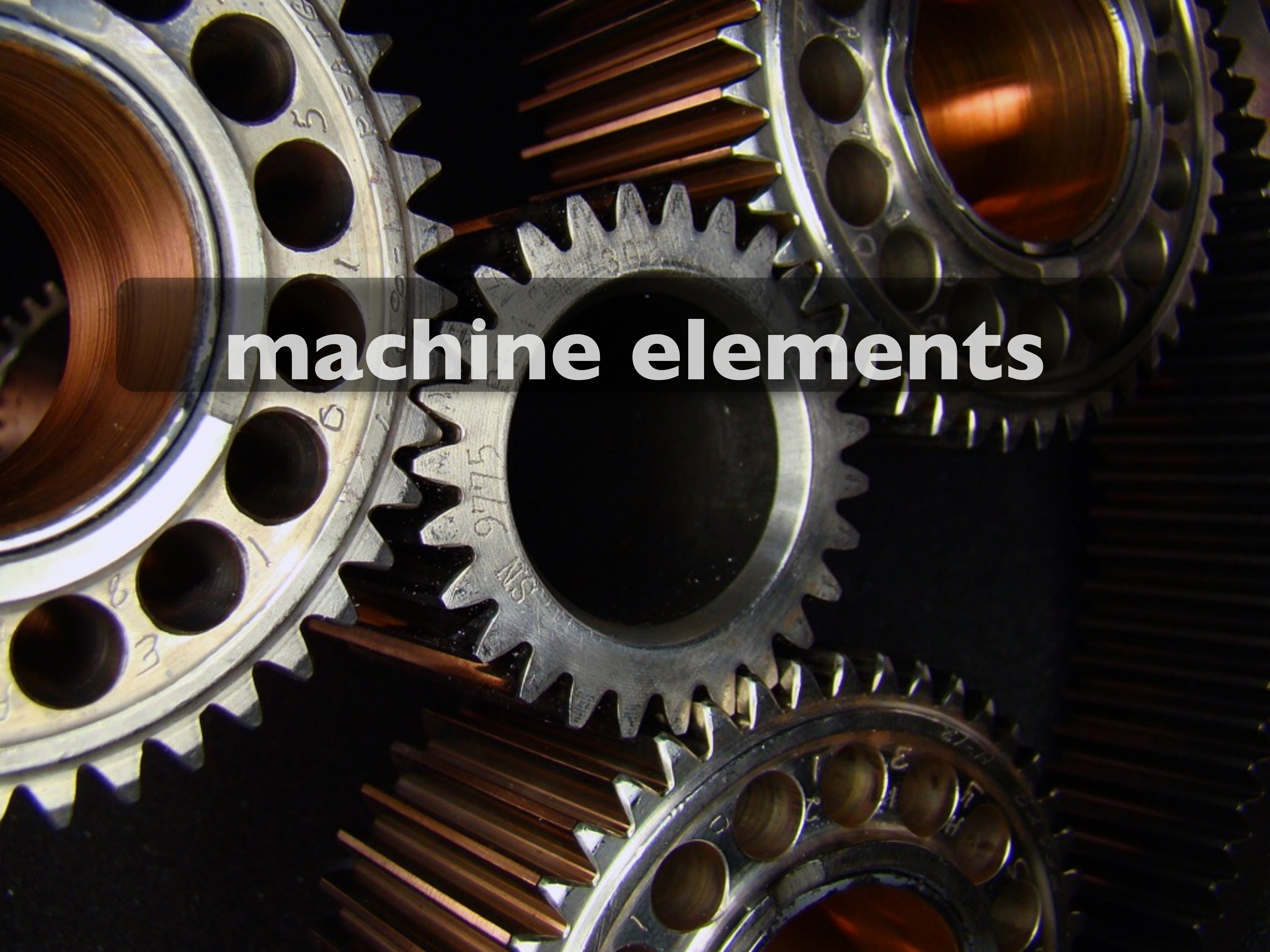
Current Amplifier

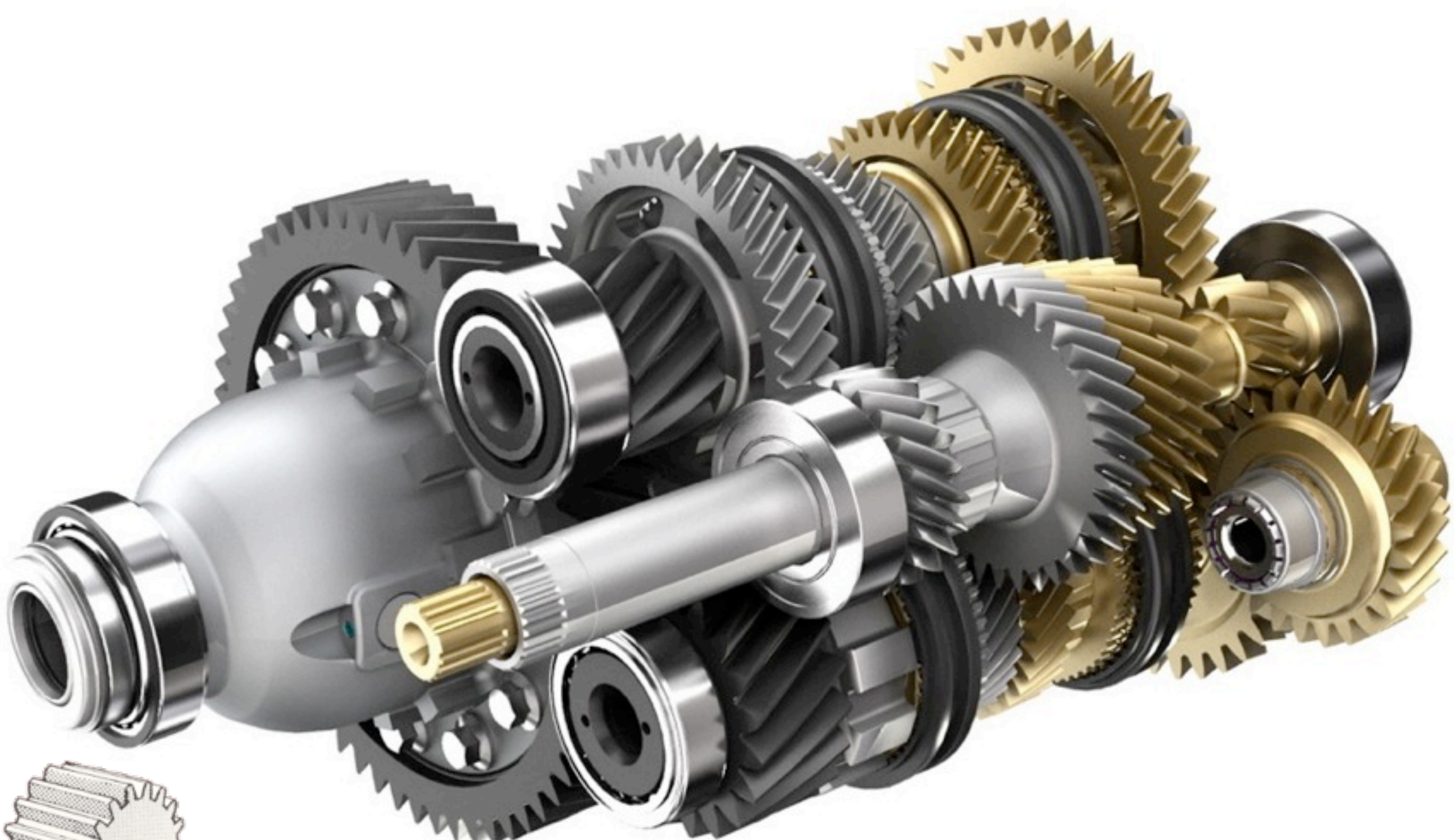


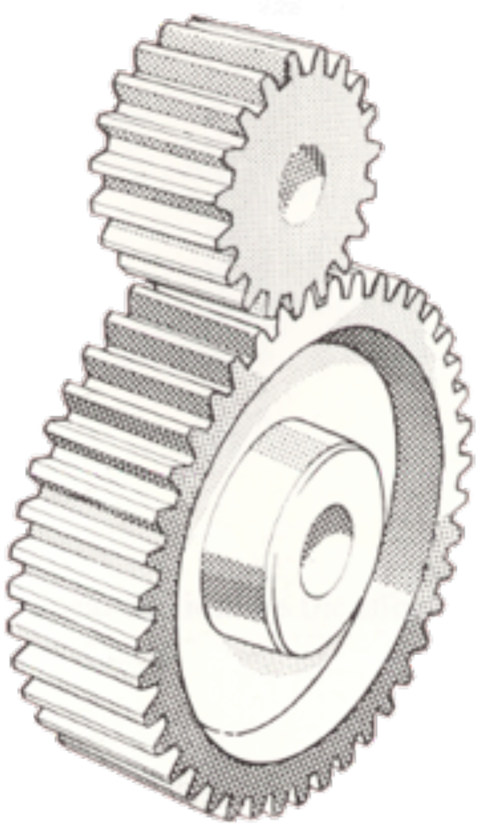
- Takes an information signal (usually an analog voltage) from the computer and drives the requested amount of current through the actuator.
- Note that this is a *current drive* scenario, not a voltage drive. Motor torque is proportional to current, regardless of speed, so we can essentially ignore the motor's electrical dynamics.
- Two common types are Pulse Width Modulation (PWM) and Linear. KJK prefers linear amplifiers for their high bandwidth and reduced electrical noise.

Current Amplifier Circuit



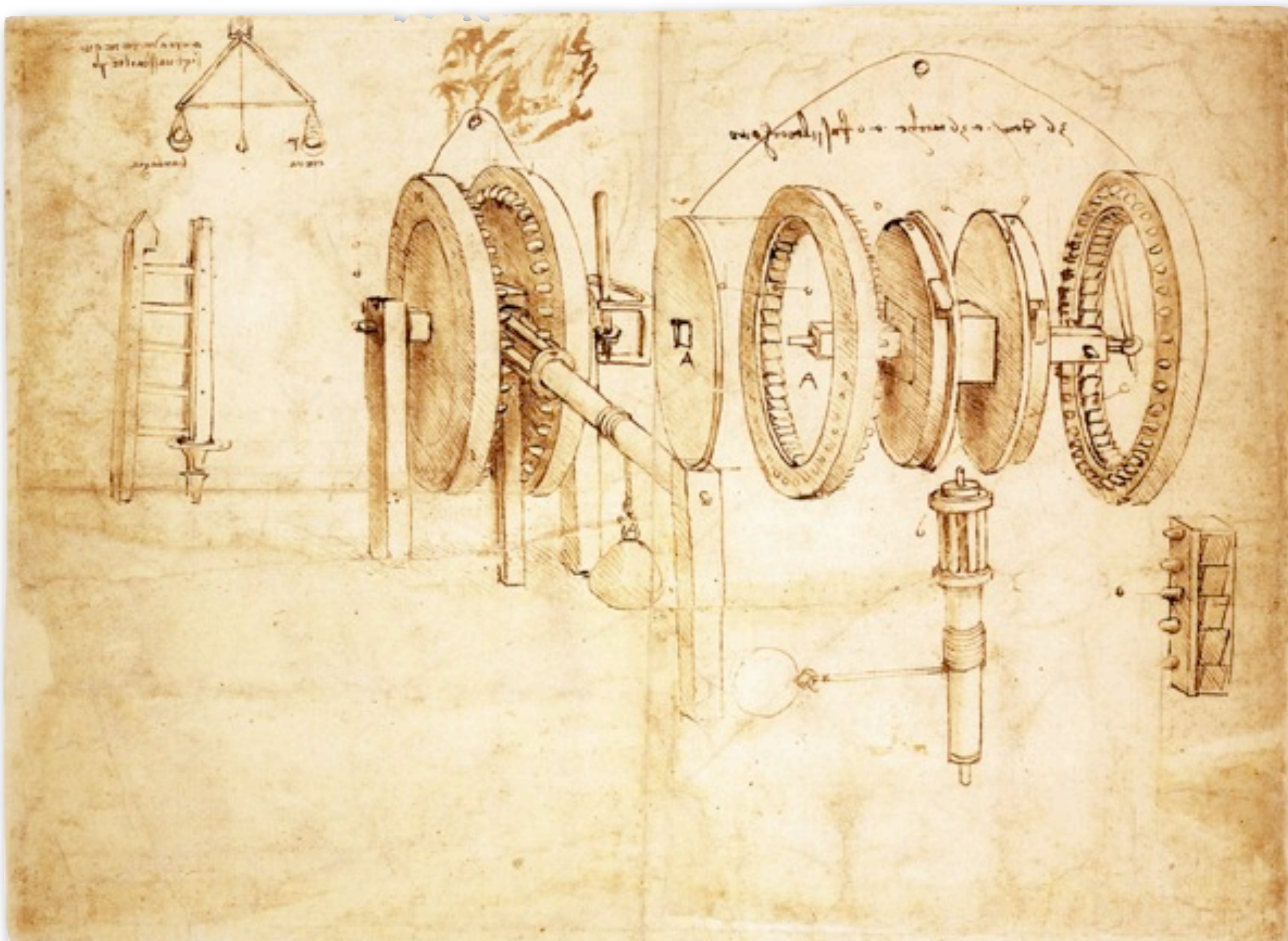

machine elements





$$N = \frac{\omega_{\text{in}}}{\omega_{\text{out}}} = \frac{\tau_{\text{out}}}{\tau_{\text{in}}} = \frac{n_{\text{out}}}{n_{\text{in}}} = \frac{r_{\text{out}}}{r_{\text{in}}}$$

Speed Torque Teeth Radius

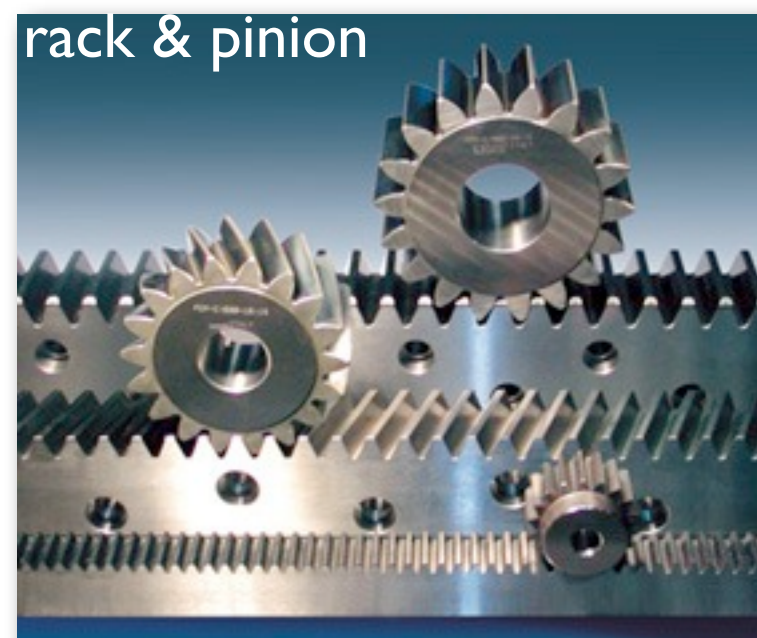



spur

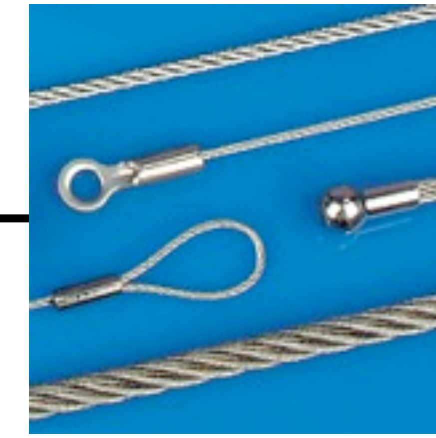

helical


crossed
helical
MORSE

FIGURE 6.14 Hypoid gears. (Courtesy of Gleason Works.)



Capstan Drive



Most haptic interfaces use a capstan drive, with thin stranded cables from a company like Sava Industries.

- The rotation of the motor shaft is coupled to the rotation of a larger drum or the motion of a linear stage by wrapping cables around a capstan.
- When pre-tensioned, cables provide a very stiff connection with zero backlash.
- We don't use belts or gears because we need motion to be smooth and efficient. Users dislike vibration.

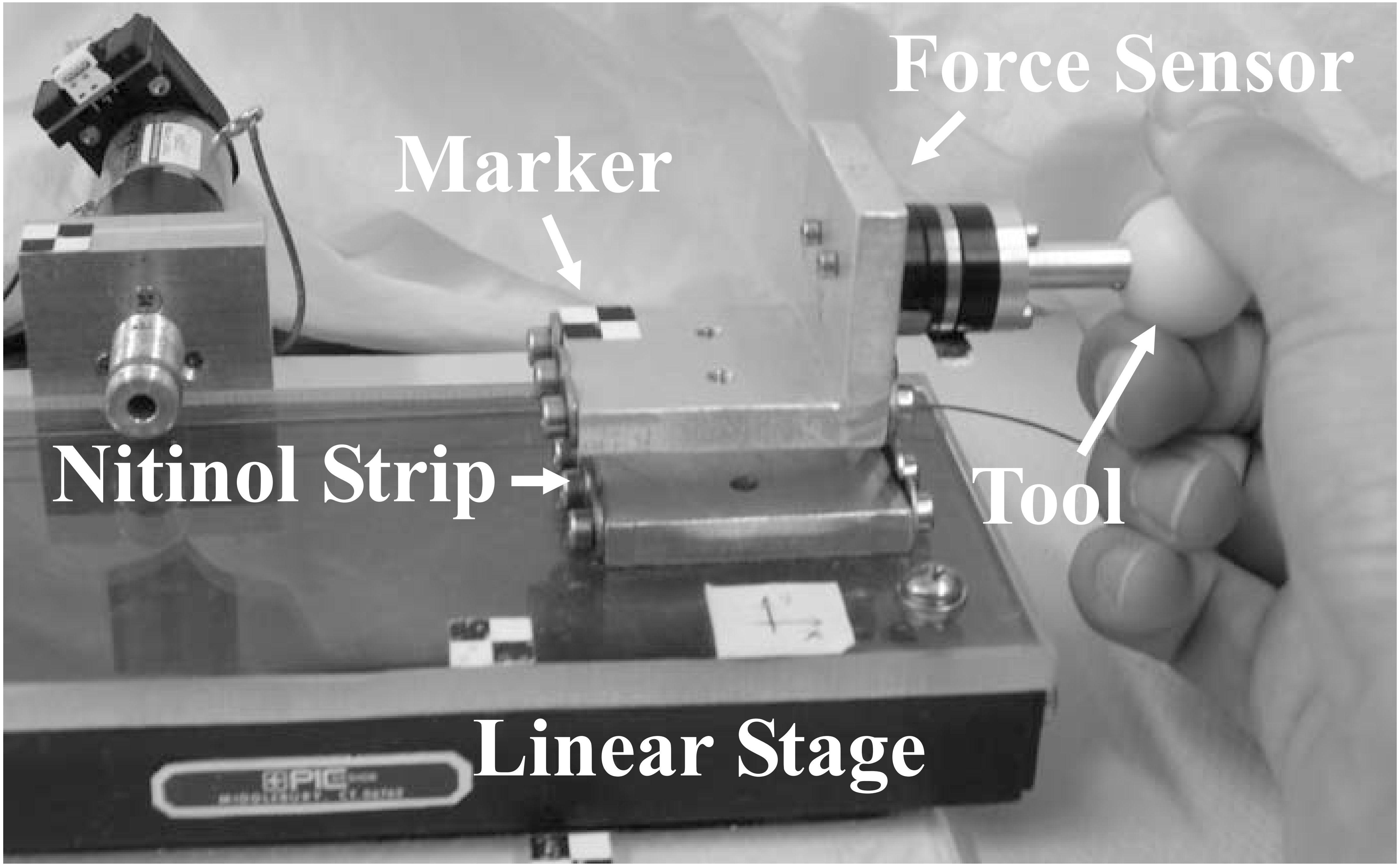
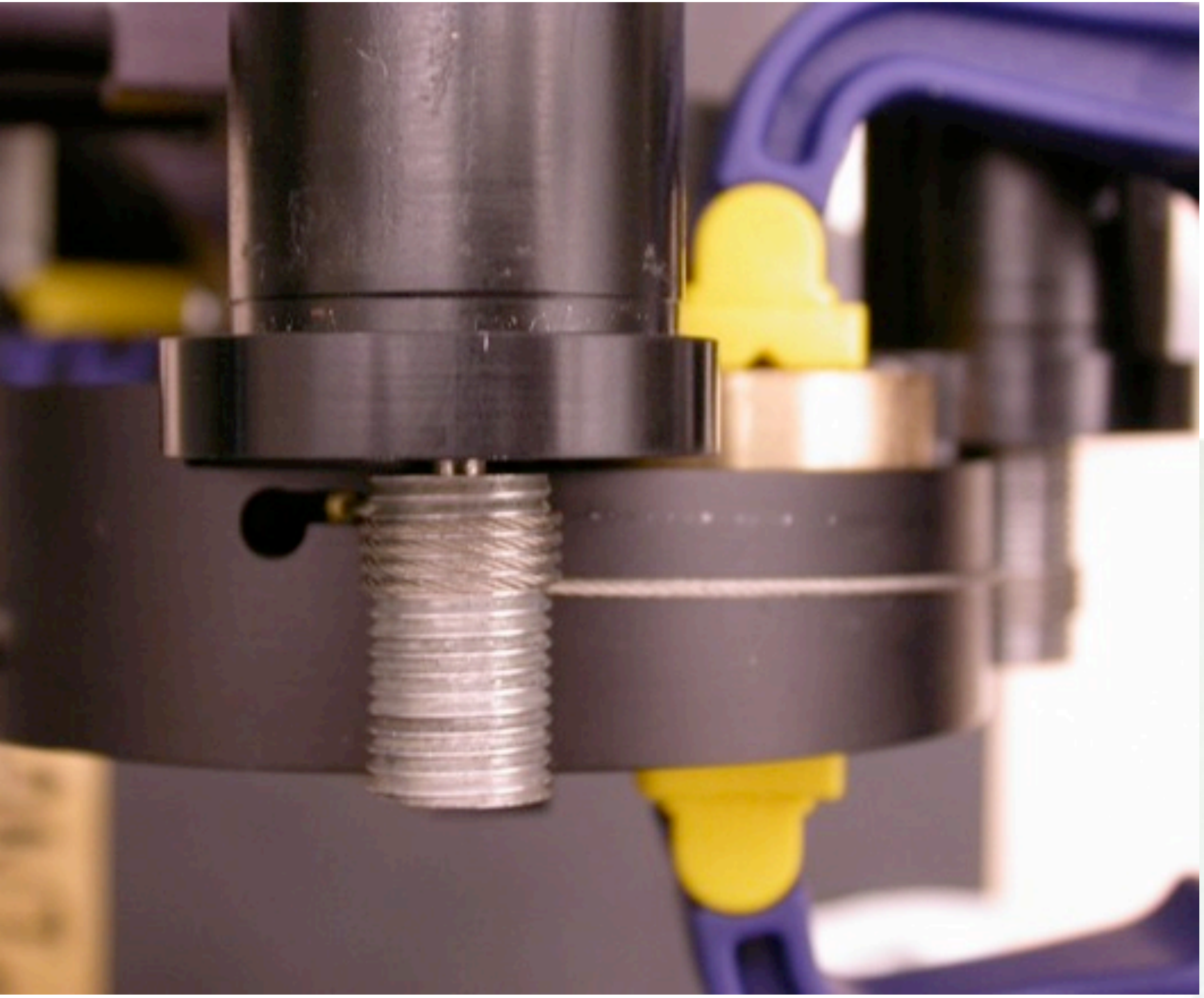
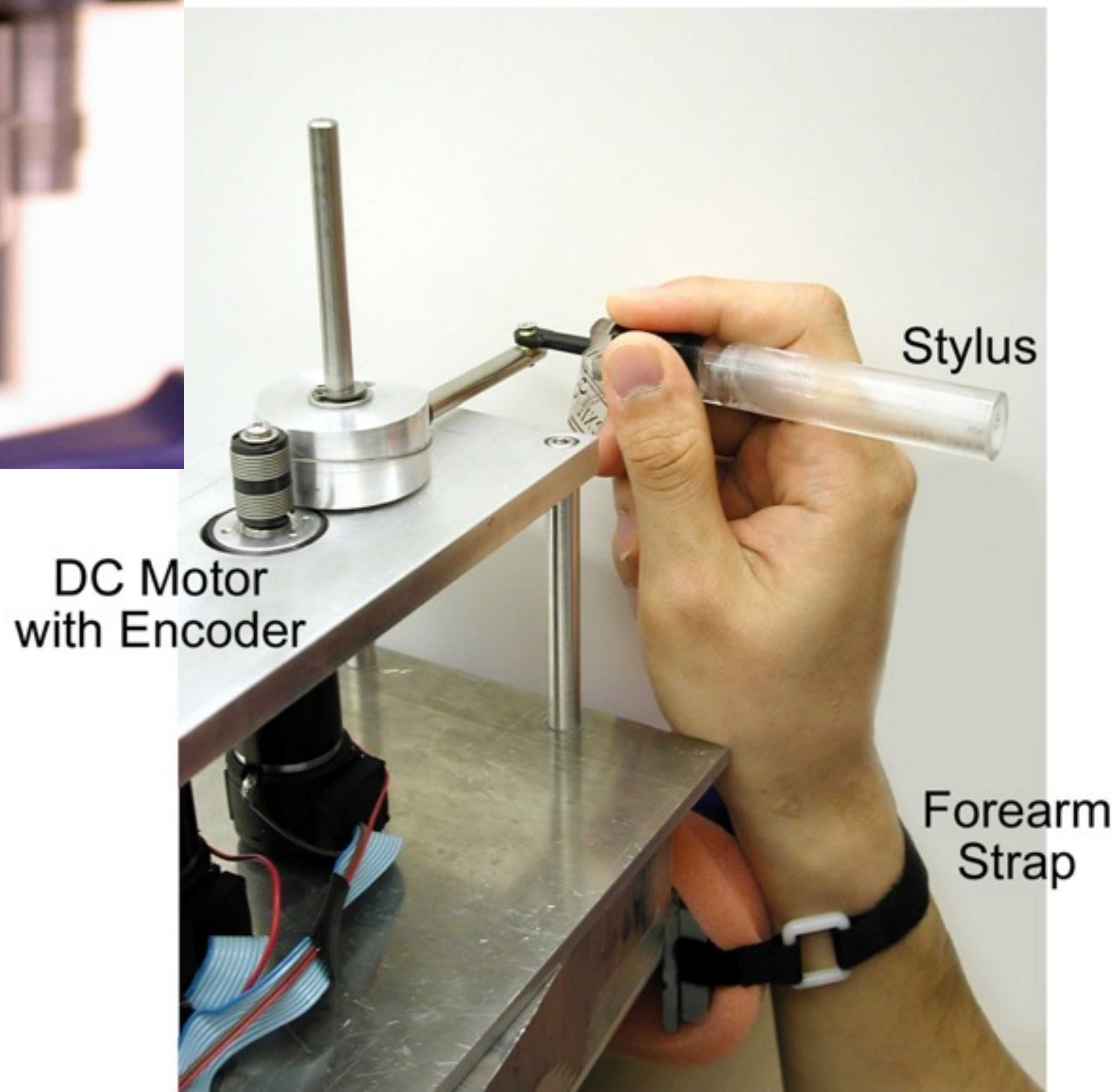
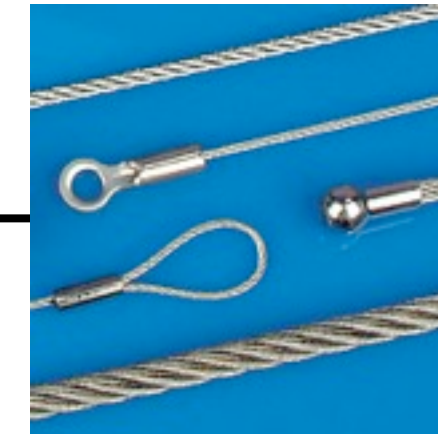


Image from Marayong, Na, and Okamura (ICRA 2007)




Stylus
DC Motor
with Encoder
Forearm
Strap

Capstan Drive



- The gear ratio is the ratio of the diameters (or equivalently the ratio of the radii).

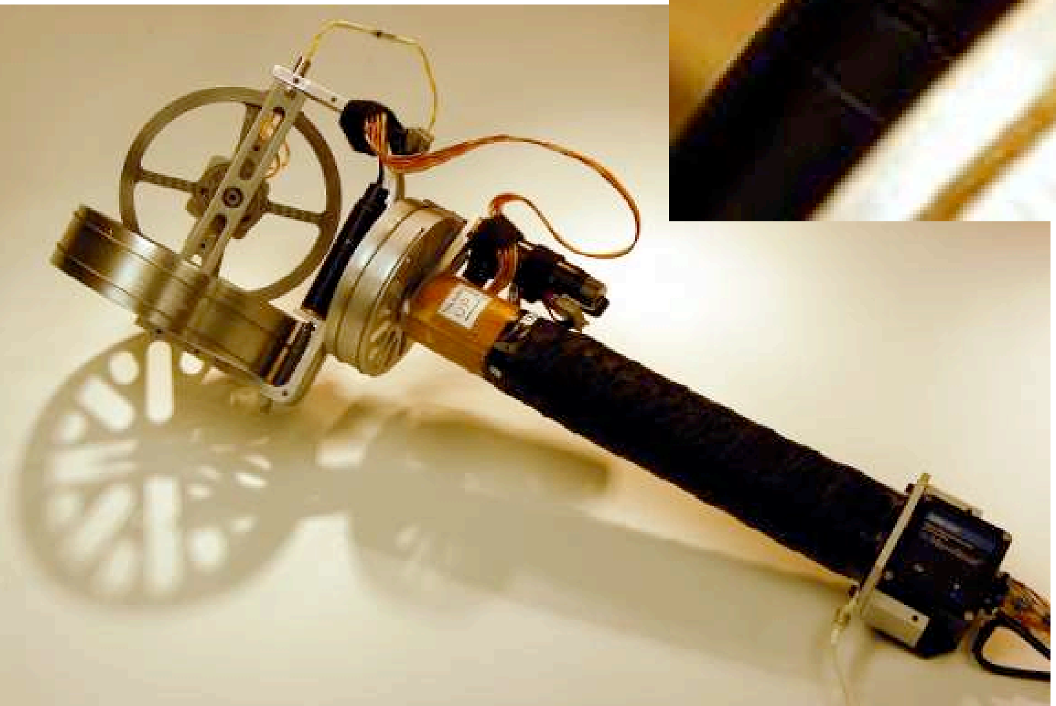
$$\rho = \frac{d_d}{d_c}$$

- The drum is almost always larger than the capstan, so rho is greater than one.

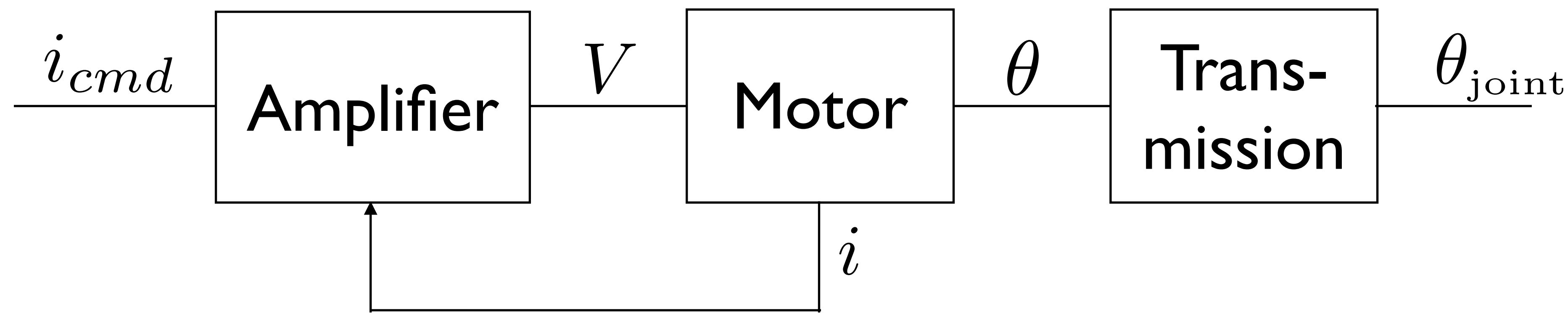
$$\tau_d = \rho\,\tau_m \qquad \omega_m = \rho\,\omega_d$$

- The drum torque is greater than the motor torque.
- The motor speed is greater than the drum speed.
- A drawback - the user feels amplified versions of the motor’s inertia and friction.

Some material adapted from slides by A. Okamura and W. Provancher



Images from the Masters thesis of Kyle Winfree, "An Ungrounded Haptic Torque Feedback Device: The iTorqU"



i_{cmd}
Amplifier
V
Motor
θ
Trans-
mission
θ_{joint}
i

A Biological Inspiration

Mechanical Structure

Bones	Frame / Links
Joints	Joints

Actuators

Muscles	Electric Motors
	Hydraulics
	Pneumatics
	SMA, etc.

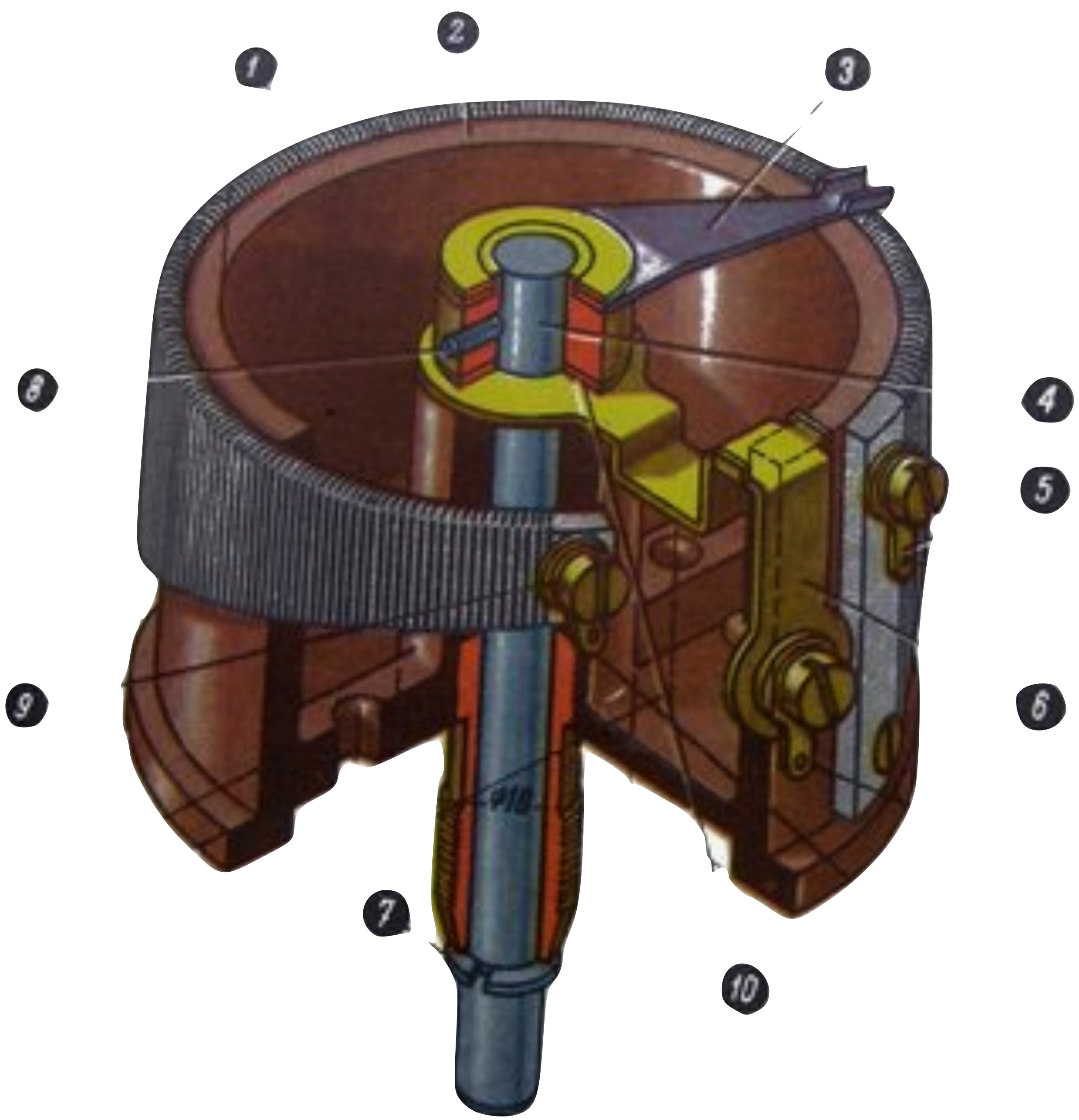
Sensors

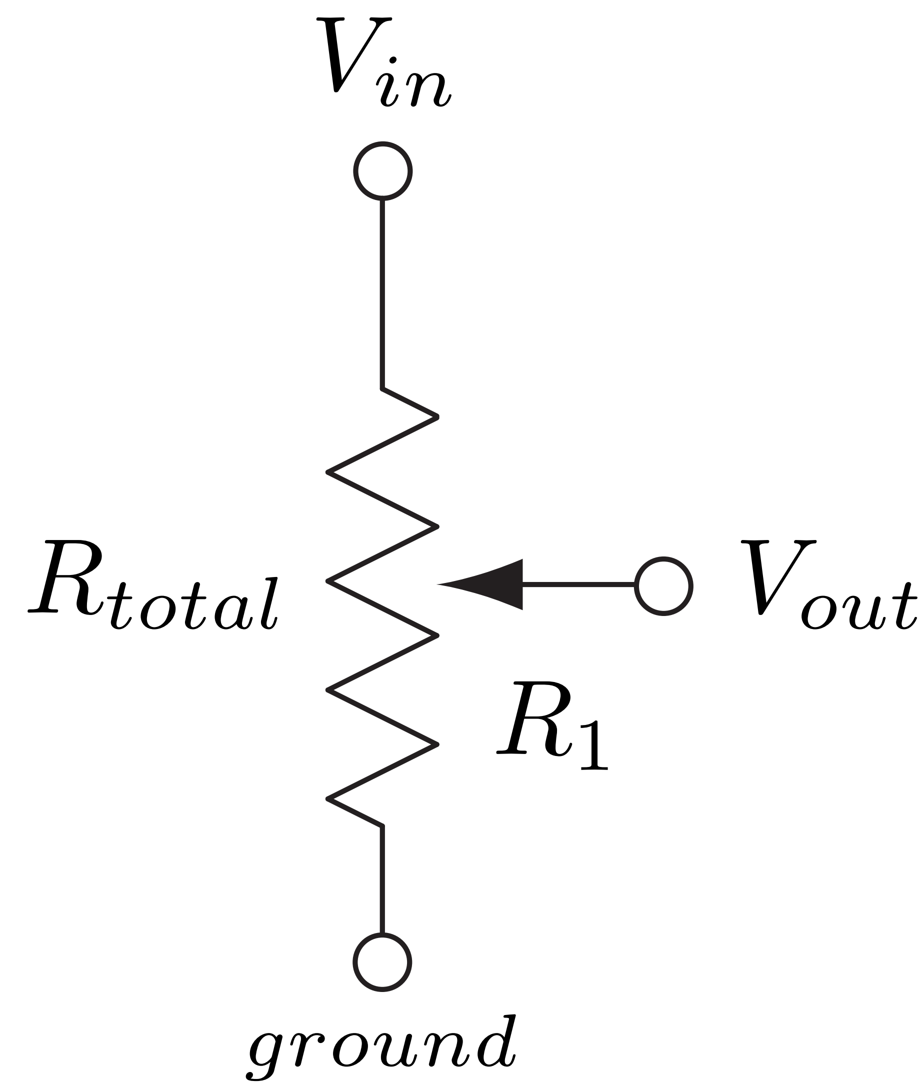
Kinesthetic	Encoders
Tactile	Load Cells
Vision	Vision
Vestibular	Accelerometers

Controller

Brain	Computer
Spinal Cord Reflex	Local feedback

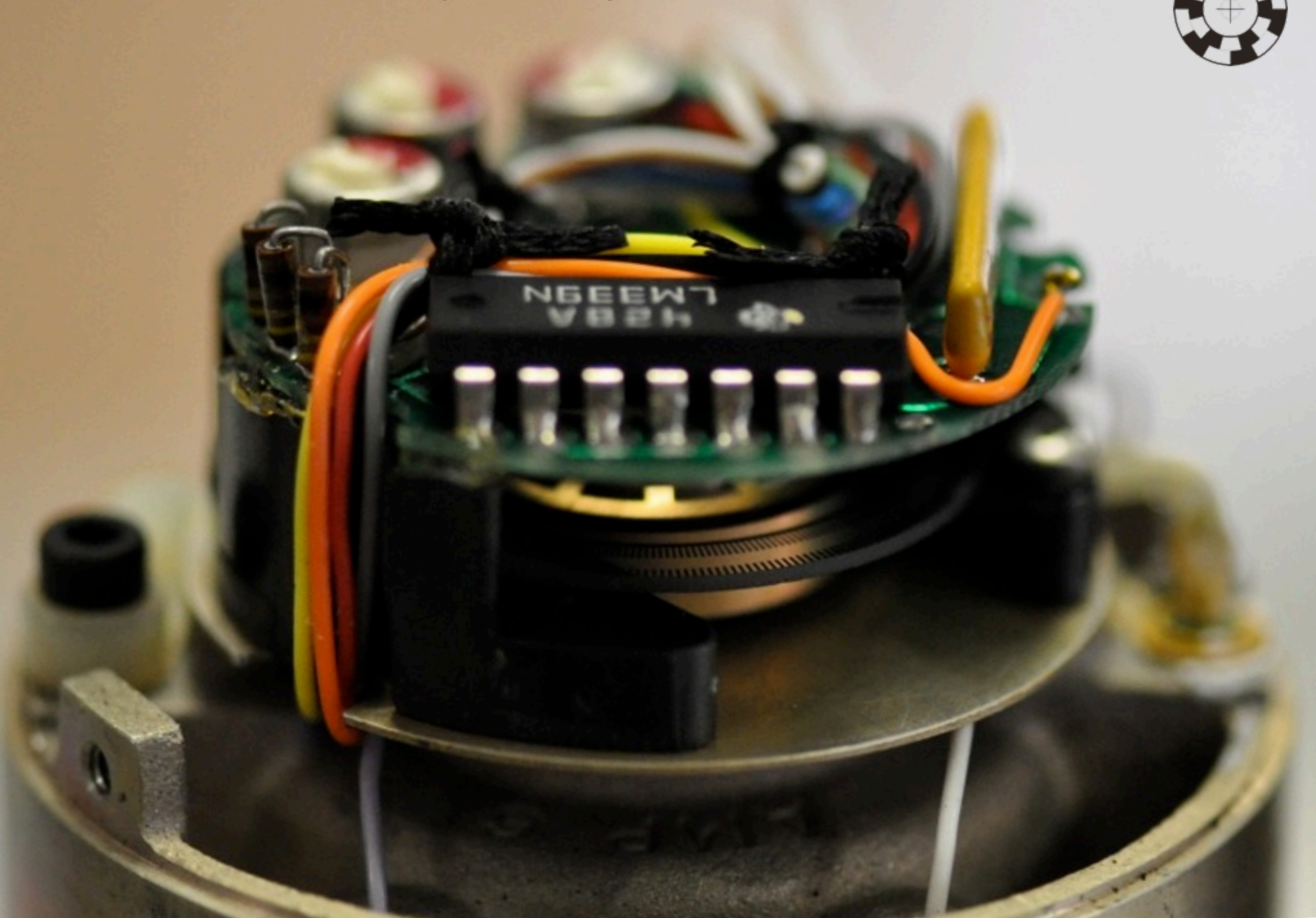
potentiometers

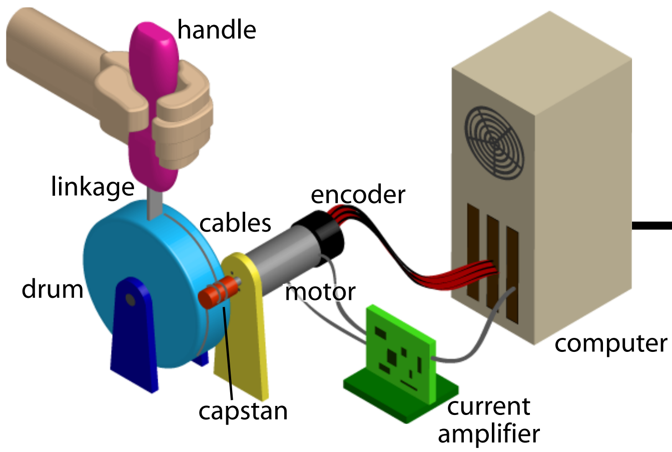




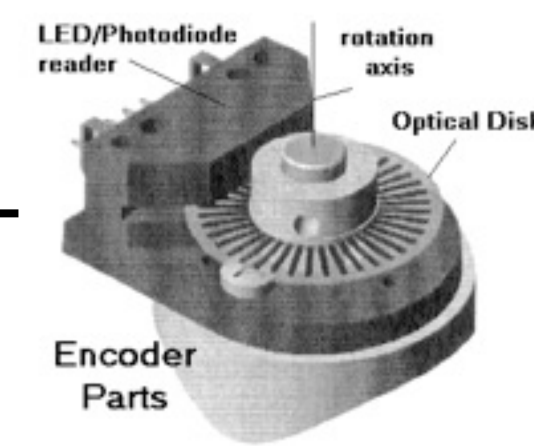
$$V_{out} = \frac{R_1}{R_{total}} V_{in}$$

Puma260 base-joint optical encoder





Encoder

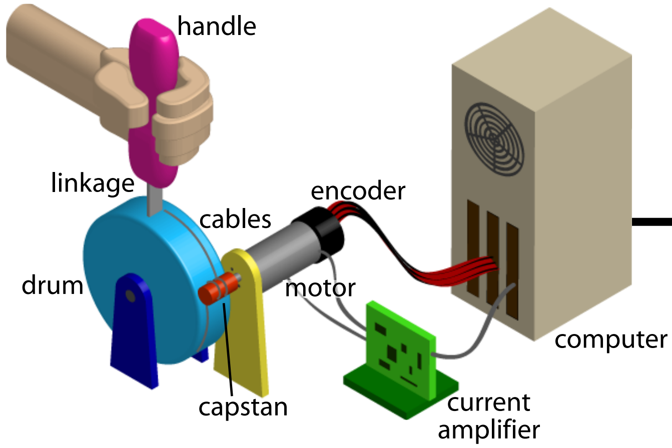


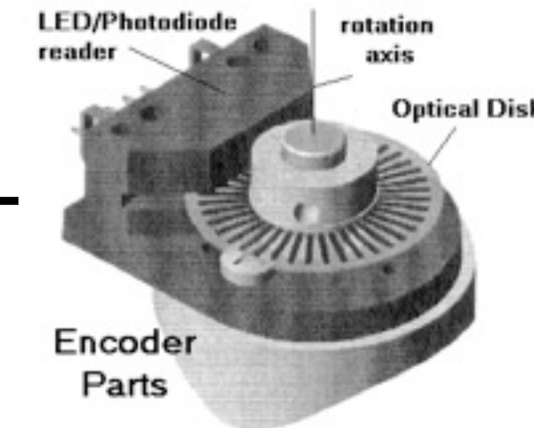
The most common motion sensor in haptics is the incremental optical encoder, often by Agilent.

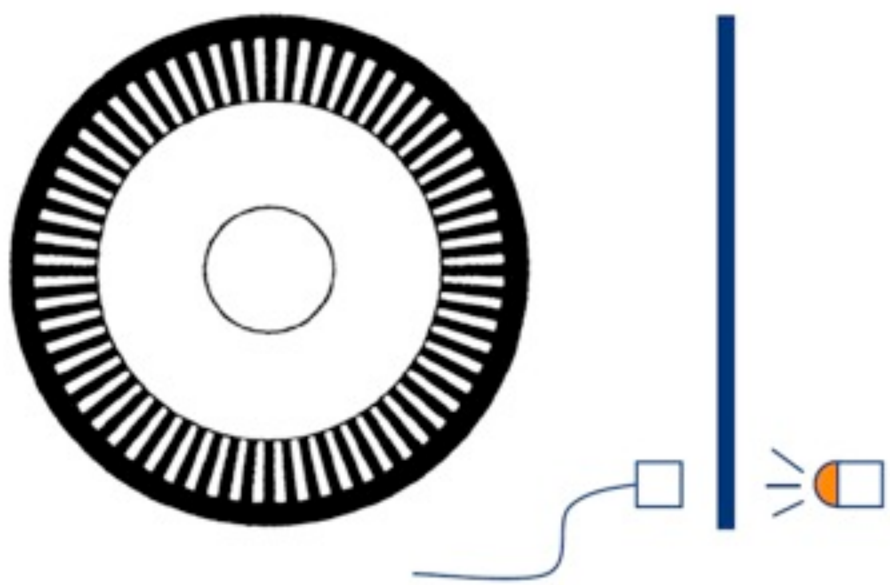
- A thin disk is attached to the rotating shaft whose angle you want to measure, usually the motor.
- The disk has slits cut into it in a regular pattern.
- A light shines on the disk on one side, and photo sensors are located on the opposite side.
- Produces a number of pulses per revolution, with higher resolution being more expensive.

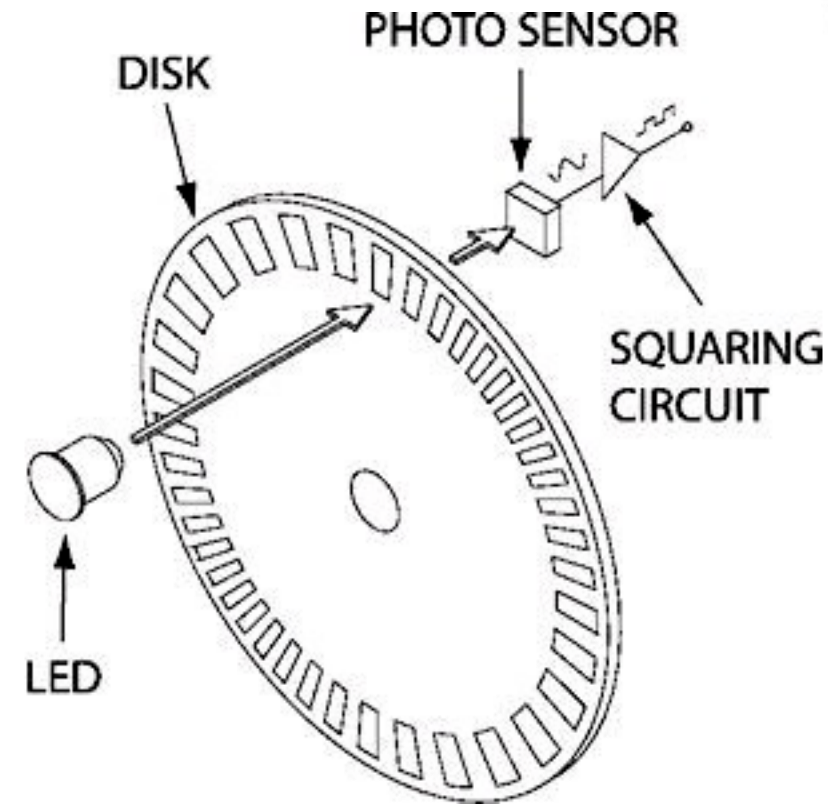
Some material adapted from slides by A. Okamura and W. Provancher

Encoder



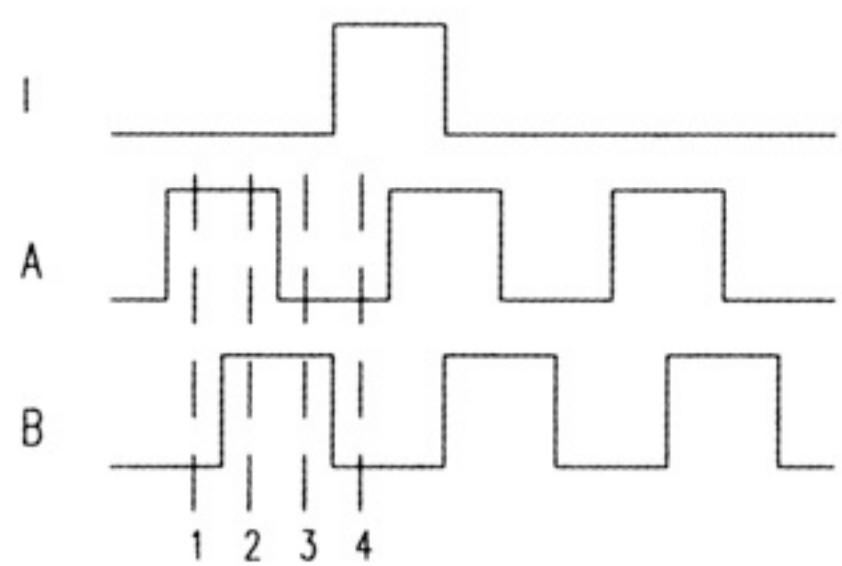






$$\Delta = \frac{2\,\pi}{4\,n}$$

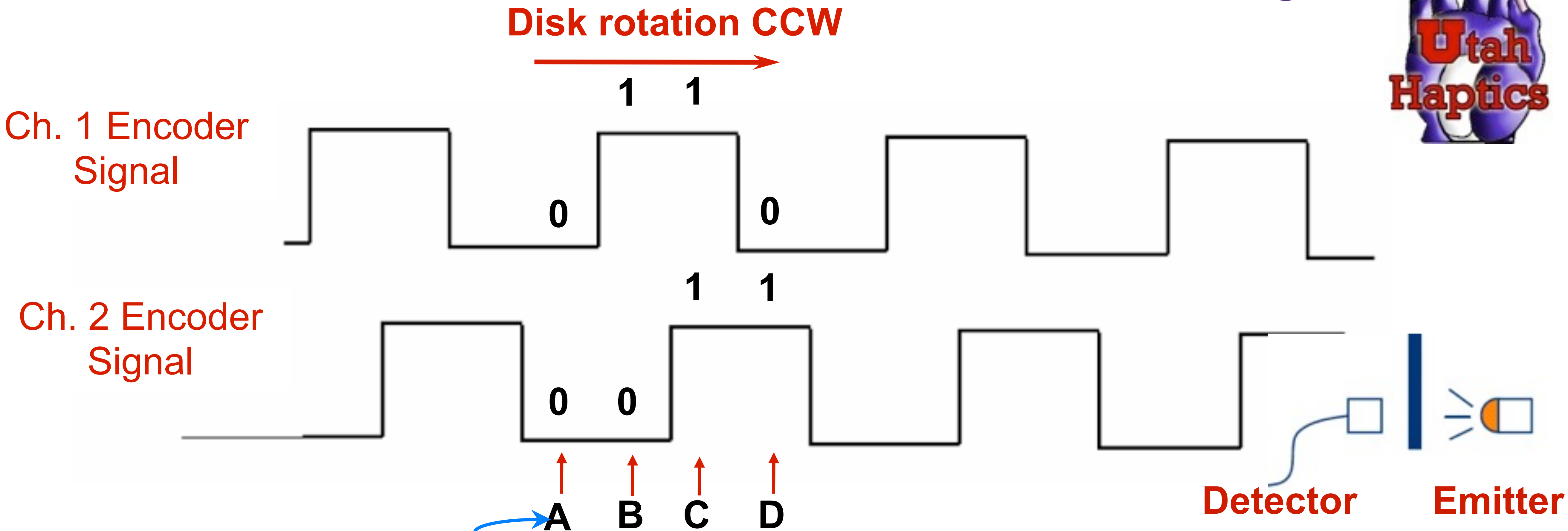
Two channels of pulses, 90 degrees out of phase: quadrature



State	Ch A	Ch B
S_1	High	Low
S_2	High	High
S_3	Low	High
S_4	Low	Low

Some material adapted from slides by A. Okamura and W. Provancher

Quadrature Encoder States & Decoding



Encoder States

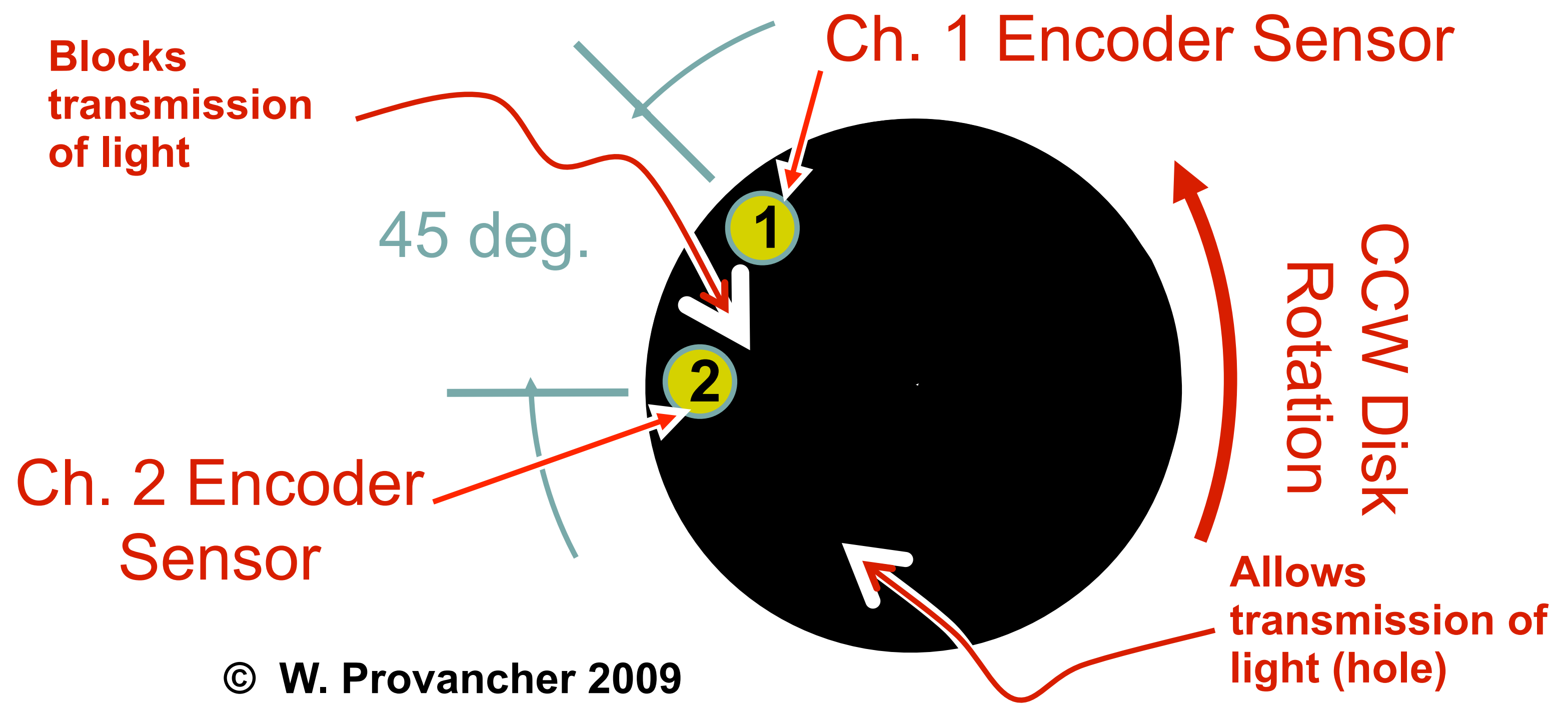
Disk rotation CCW →

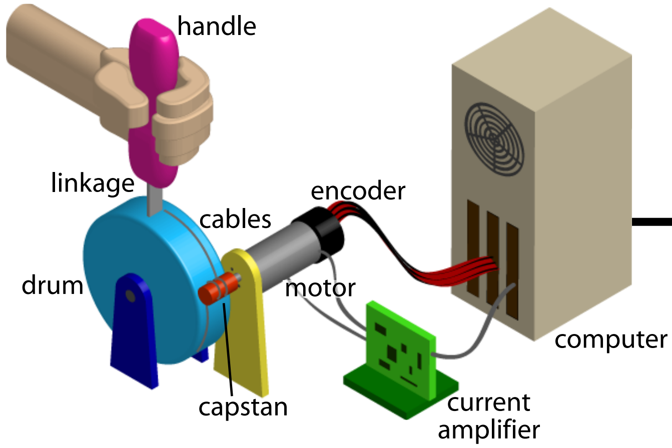
	A	B	C	D
Ch. 1	0	1	1	0
Ch. 2	0	0	1	1
	A	B	C	D

← Disk rotation CW

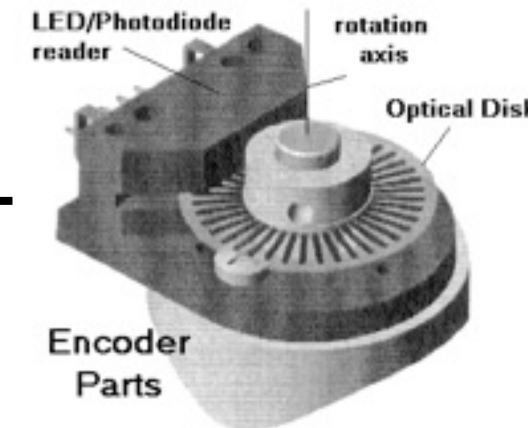
Simplified Encoder Disk

(2 CPR, 8 PPR) (shown in state A)





Encoder

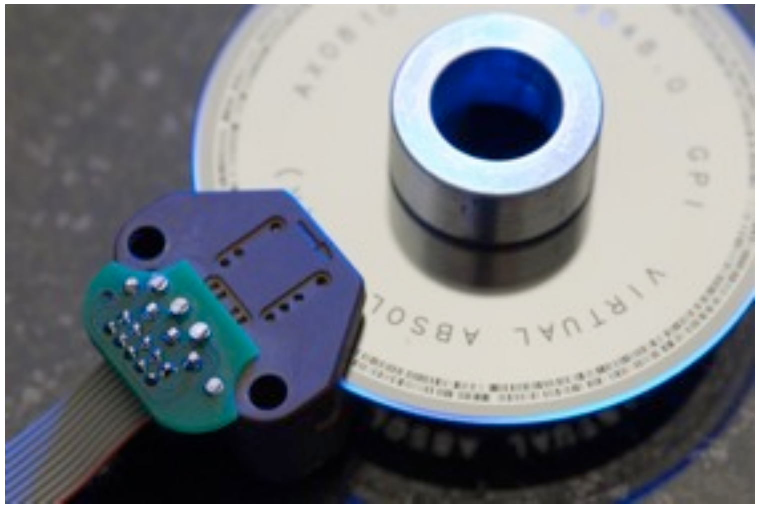


Ramifications of using incremental of optical encoders:

- The system has no knowledge of absolute position, because it's always just counting pulses.
- How can you solve this?
  - Calibration pose (SensAble)
  - Secondary sensors with absolute readings (da Vinci)
- Sometimes problems occur at high velocities.
- No noise on position, but uncertainty due to resolution, and significant noise on velocity.

$$\theta_m = \Delta(Q - Q_{zero})$$

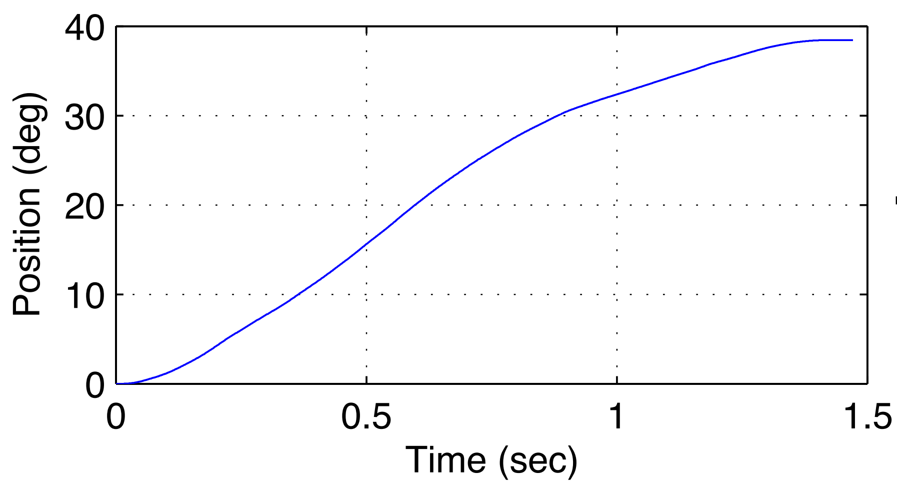
absolute encoders



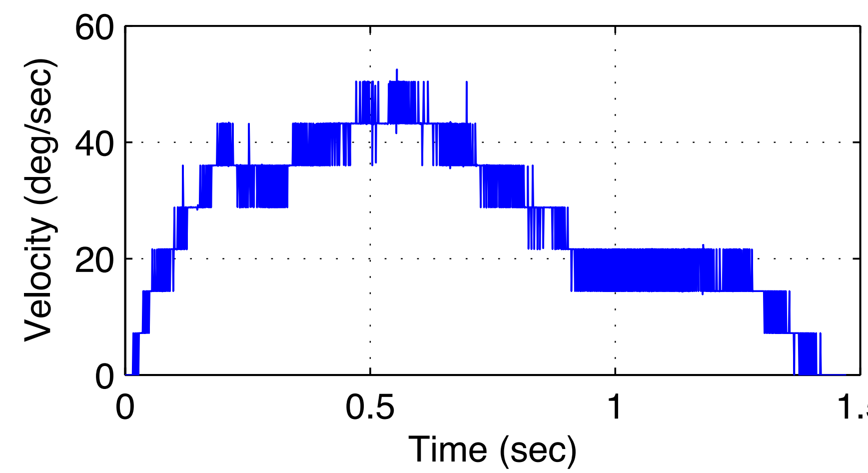
Differentiation of Position

discretized and quantized

usually requires filtering (which adds time delay)

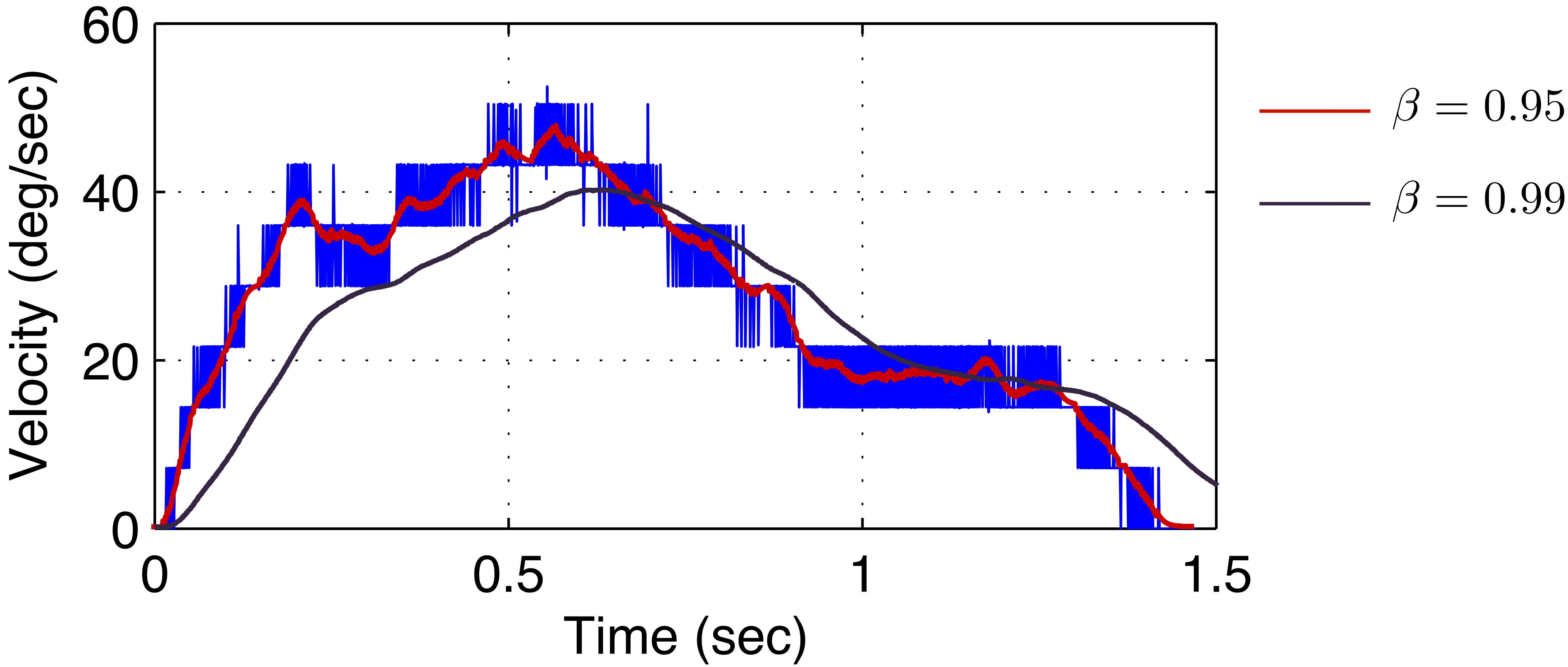


$$\frac{d}{dt}$$



Infinite horizon (fading-memory) low-pass filter

$$\hat{v}_i = \beta \hat{v}_{i-1} + (1-\beta) v_i \qquad 0 < \beta < 1$$

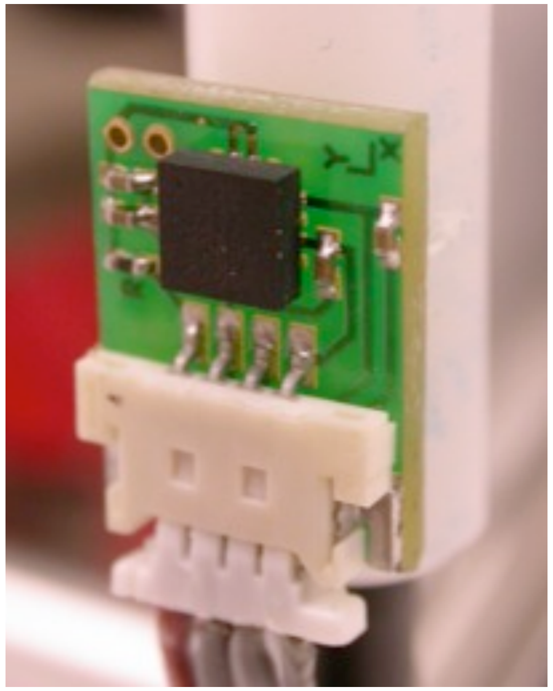


Equivalent analog bandwidth

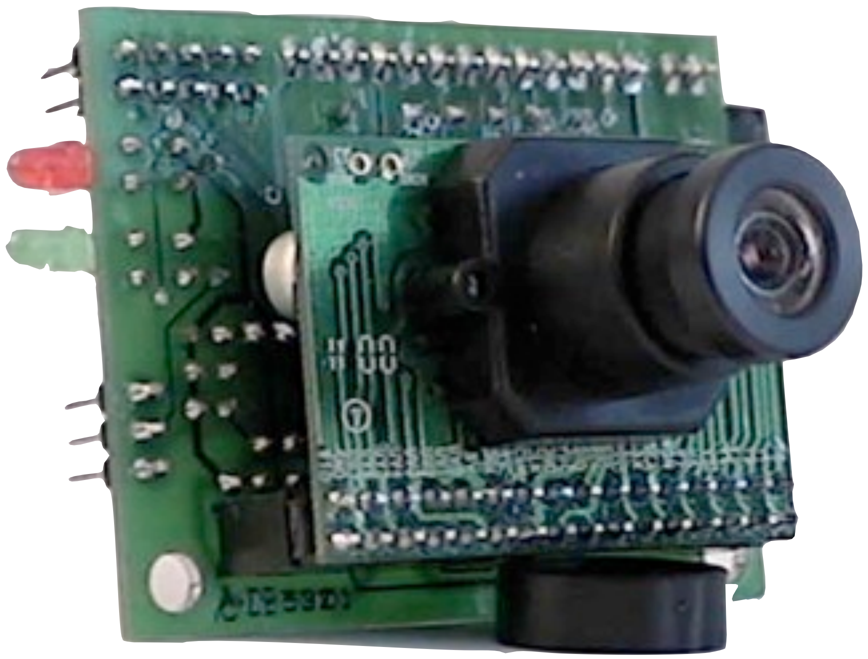
$$\omega = \frac{1}{\tau} = \frac{1-\beta}{\beta} T$$

other sensors

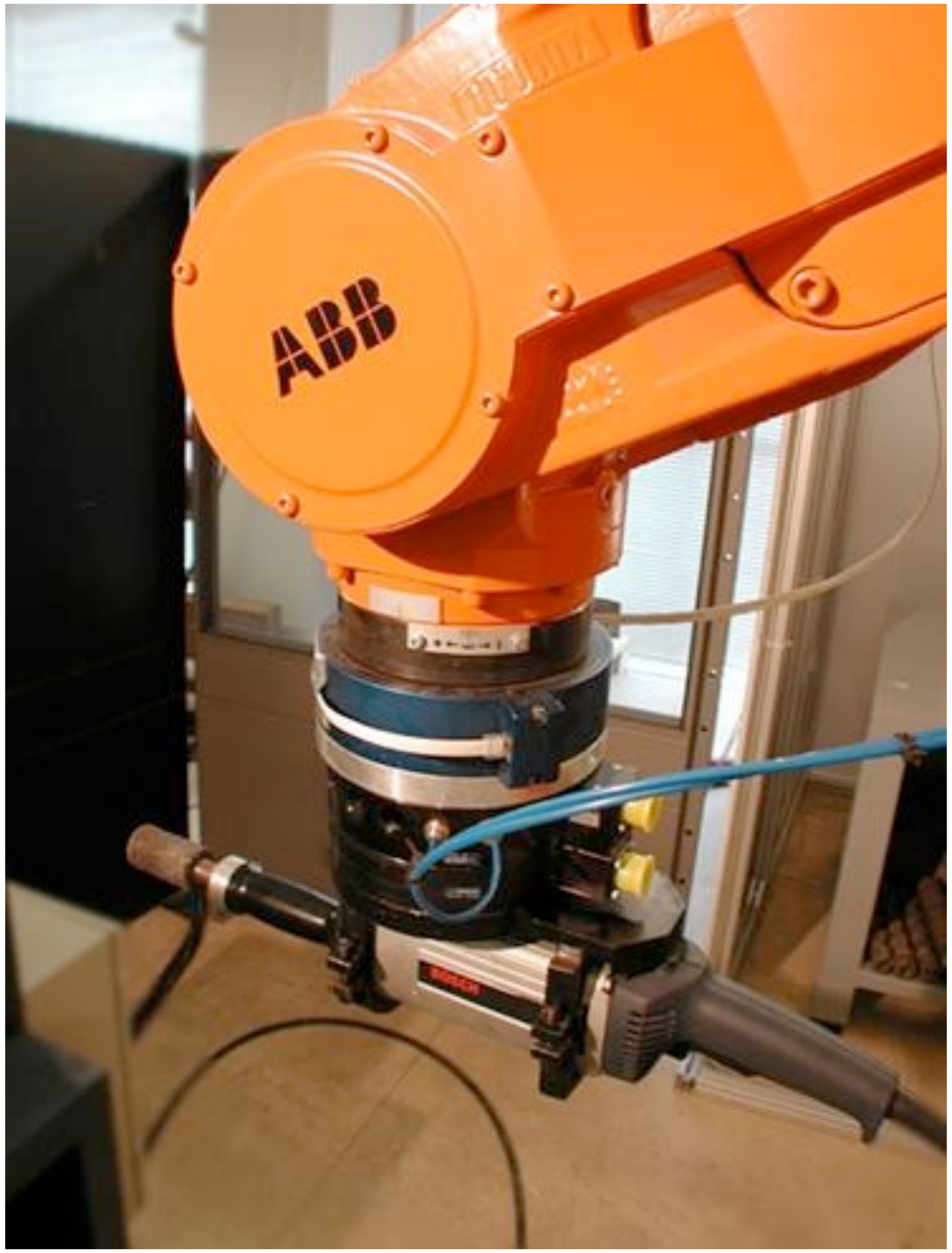
Acceleration



Vision



Force / Torque



What sensors do you see?

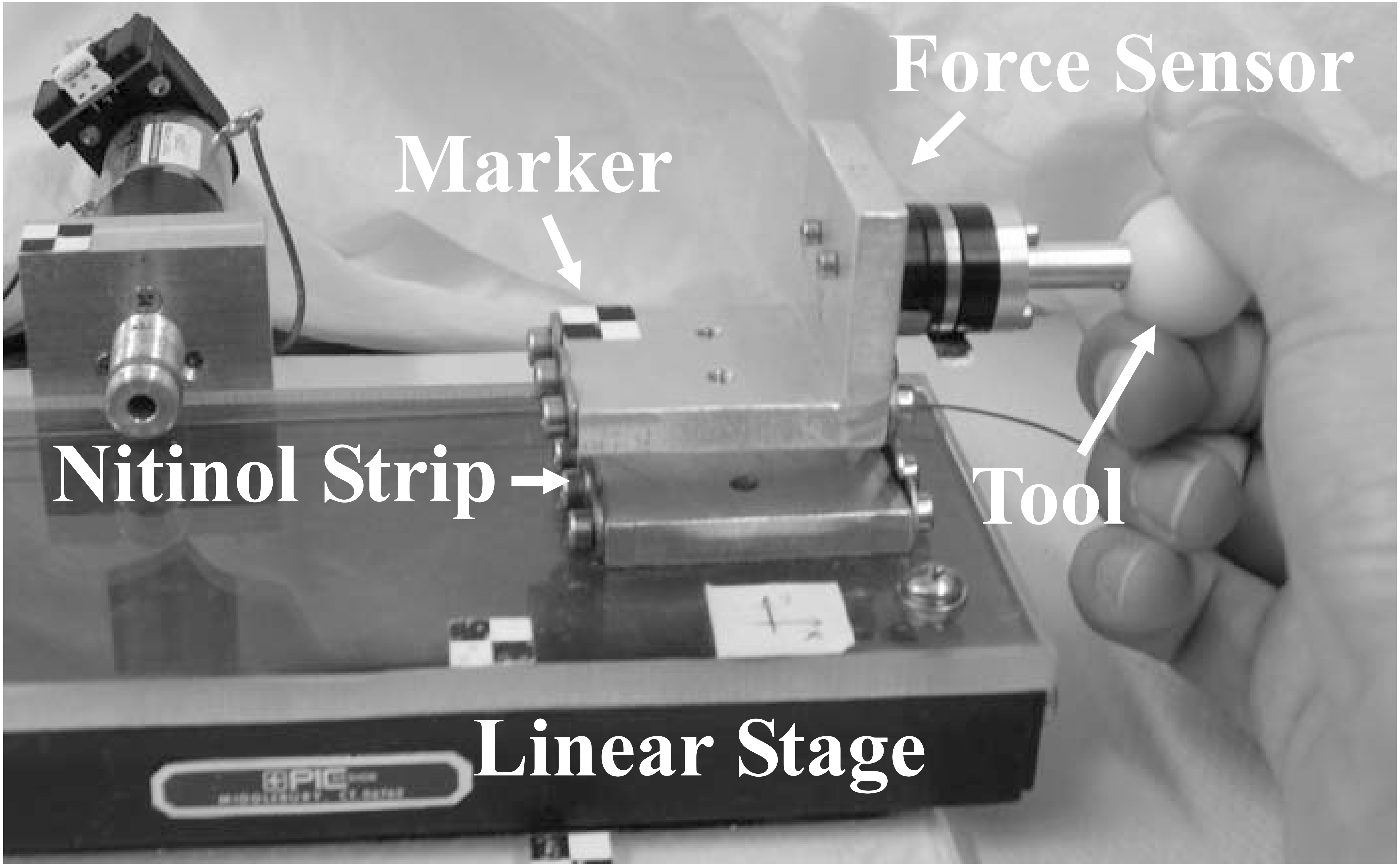
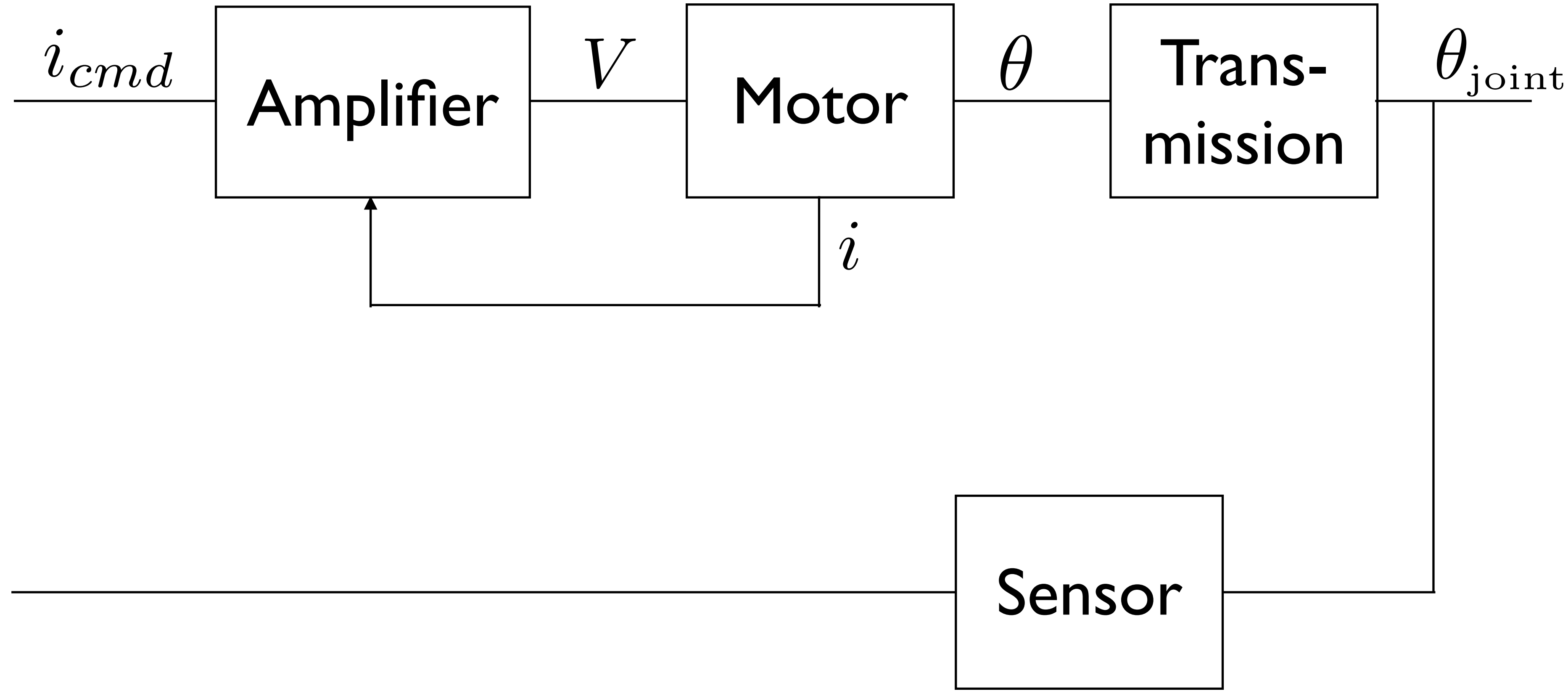


Image from Marayong, Na, and Okamura (ICRA 2007)


i_{cmd}
Amplifier
V
Motor
θ
Trans-
mission
θ_{joint}
i
Sensor