Rainbow

Haptic devices

Claudio Pacchierotti

CNRS

The Rainbow team

Currently 35 people in Rennes.

10 permanent researchers from Inria, CNRS, INSA, and Univ. Rennes 1

1 permanent engineer

19 Ph.D. students

4 post-doc

4 temporary engineers

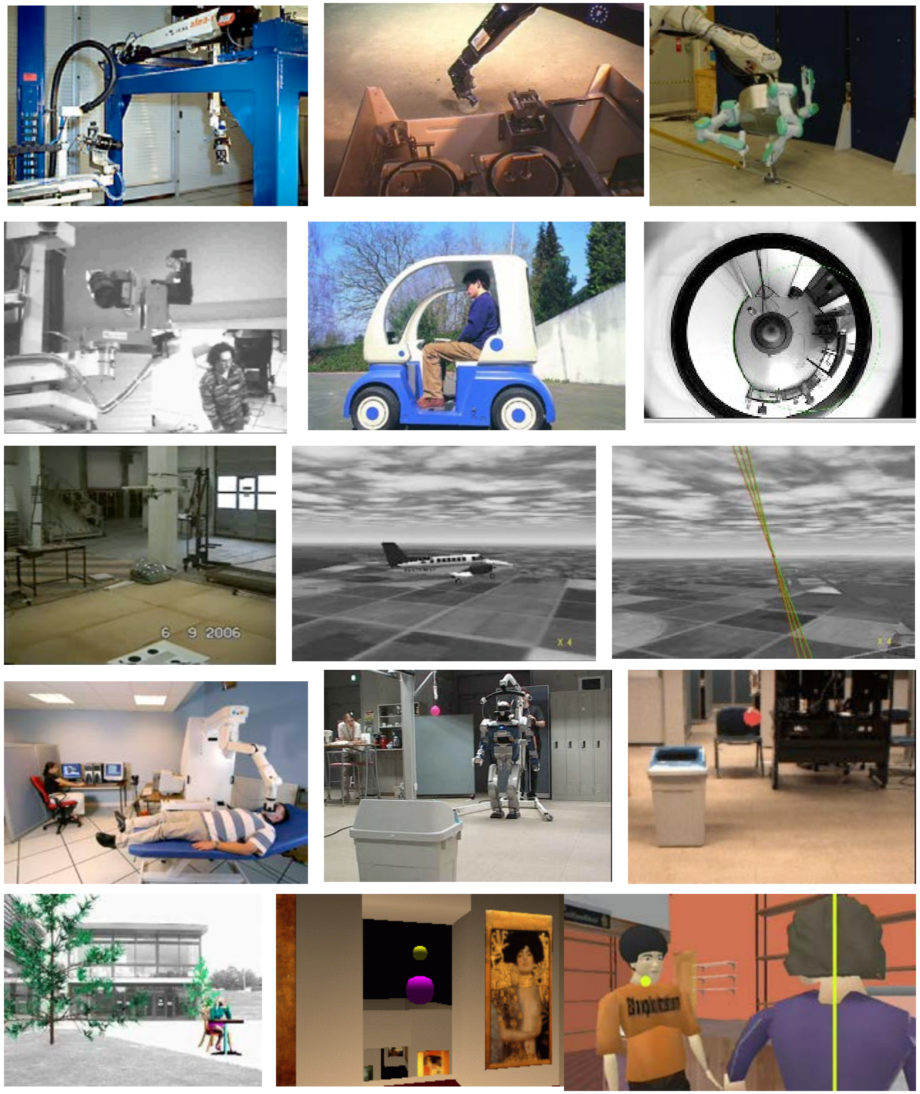
Objectives

Develop generic methods in

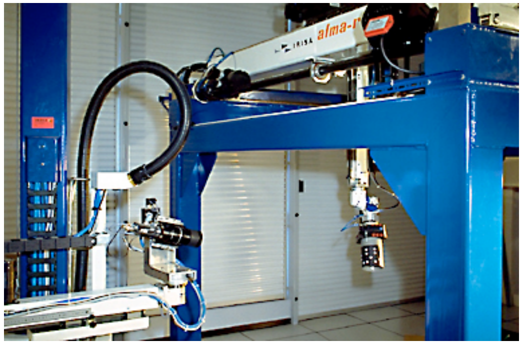
- real time visual tracking
- visual servoing
- control

that we want to apply for:

- vision-based manipulation
- vision-based navigation
- medical robotics
- collaborative robotics



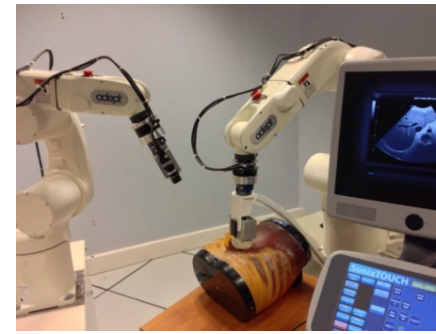
Experimental platforms



Industrial manipulators

Mobile robots

Semi-autonomous wheelchairs



Medical robots

Quadrotor UAVs

UAV flying arena with motion capture system

Humanoid robots (Romeo & Pepper)

Short bio

Education

Computer Engineering, special. in Robotics & Automation, **University of Siena**, Italy
2014: Dottorato di ricerca (doctorat)

International Mobility

2013/2014: **University of Twente**, The Netherlands, visiting student (5 months)
2014: **University of Pennsylvania**, USA, visiting student (7 months)

Postdoctoral experience

2015-2016: **Istituto Italiano di Tecnologia (IIT)**, Italy (2 years)

Current appointments

- CRCN Researcher, **Centre National de la Recherche Scientifique (CNRS)**, IRISA, Équipe Rainbow, Rennes, France (**from Dec 2016**).
- Chair of the **IEEE Technical Committee on Haptics** (**from Jan 2018**).
- Secretary of the **Eurohaptics Society** (**from June 2018**).

Rainbow

Haptic devices

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"Computer haptics is the discipline concerned with generating and rendering haptic stimuli to the human user"

–Mandayan Srinivasan (MIT Touch Lab)

Today's Outline

- What is haptics? Is it important?
- Haptic interfaces, past and present
- Grounded haptics vs. Ungrounded haptics
- Principles of design and personalization
- Latest research: mid-air haptics

What is Haptics?

- Physical interaction via touch
  - Kinesthetic and tactile perception
- Uniquely bi-lateral sensory modality
- Touching and interacting with real, virtual, and remote environments

You will see more of this next week!

Definition

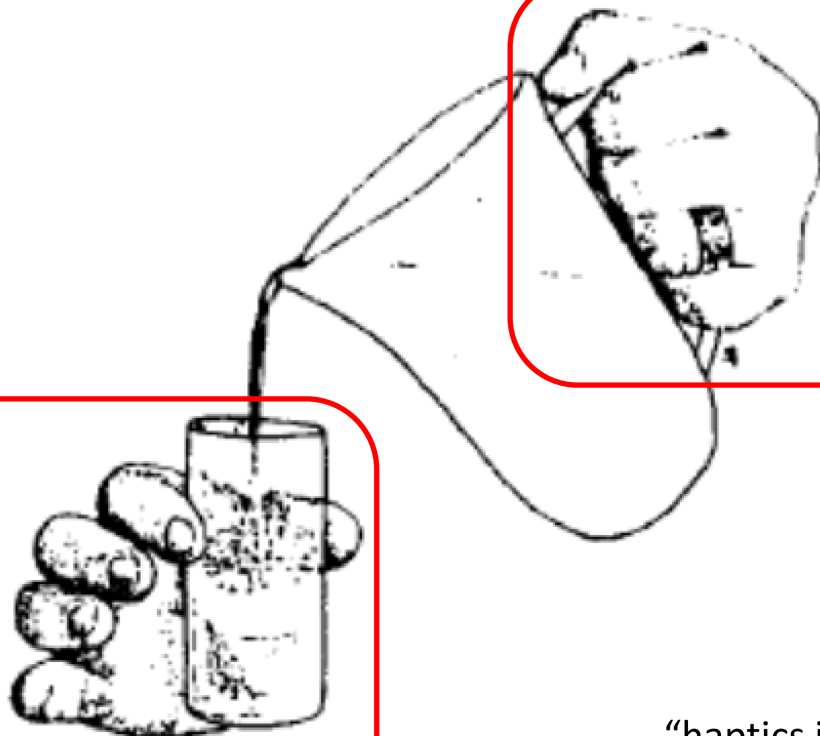
- **haptic** (*adjective*) \ˈhap-tik\
  - relating to or based on the sense of touch
  - characterized by a predilection for the sense of touch: “a haptic person”
- Etymology:
  - International Scientific Vocabulary, from Greek *haptesthai*: to touch
  - First Known Use: ca.1890

[Merriam-Webster online dictionary: http://www.merriam-webster.com/dictionary]

Nomenclature

- haptic: an adjective, as in "a haptic interface"
- haptic interaction: the act of touching objects
- haptics: use as a noun, the study/practice of haptic interaction
- haptically: making use of touch interaction
- haptic interface: device permitting human to have touch interaction with real or virtual environments

Haptics = Cutaneous and kinesthetic stimuli

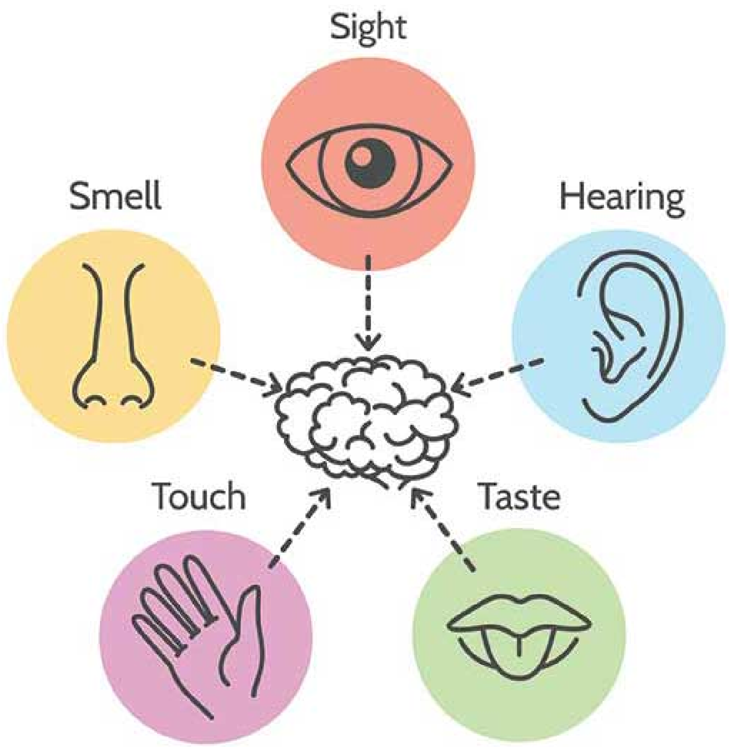


Kinesthesia
- Location/configuration
- Motion
- Force
- Compliance

Cutaneous
- Temperature
- Texture
- Slip
- Vibration
- Force

“haptics is to touch as optics is to sight”
(A. M. Okamura), 2008.

Which sense is the most important?



which sense is most valuable to you?

which would you relinquish last?

What would life be like without touch?

Living without cutaneous sensations

What would life be like without touch?

Living without kinesthetic sensations

Human haptics: tactual stereognosis

Not only the haptic sense is important, humans are also very good at it!

• Tactual = tactile = via the sense of touch.

• Stereognosis = the mental perception of threedimensionality by the senses, usually in reference to perceiving the form of solid objects by touch.

• One study (Klatzky et al., 1985) showed that subjects could identify 100 common objects almost perfectly, taking about 2 seconds per object.

• People are very good at tactual stereognosis.

What if…

you could make any surface feel fuzzy, sticky, soft...?

you could touch priceless works of art?

there was a haptic holodeck?

haptics could teach you?

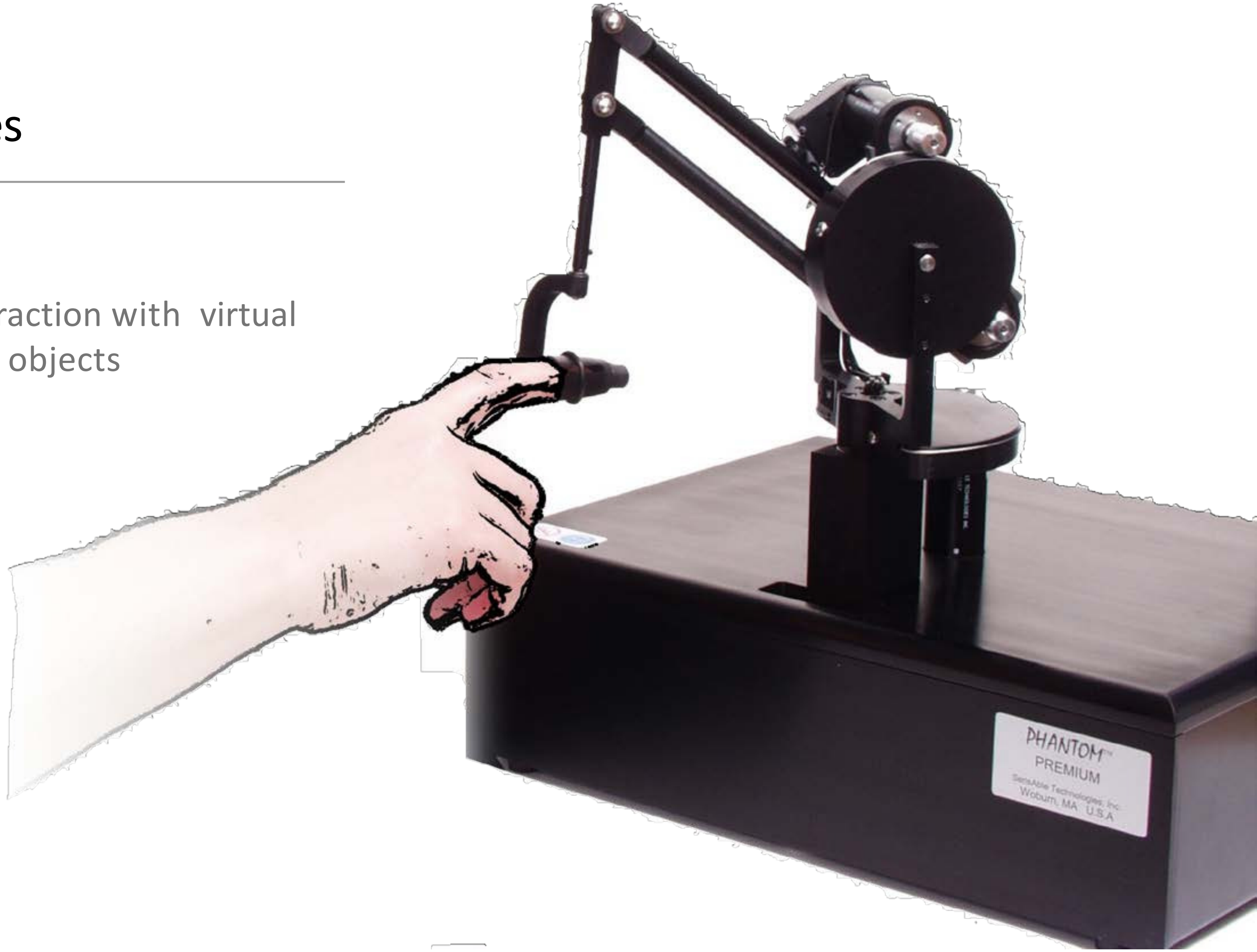
What if…

https://www.facebook.com/CentroServiziSartor/

Castelfranco Veneto, Italy
COVID-safe meeting rooms in a EHPAD

Haptic Interfaces

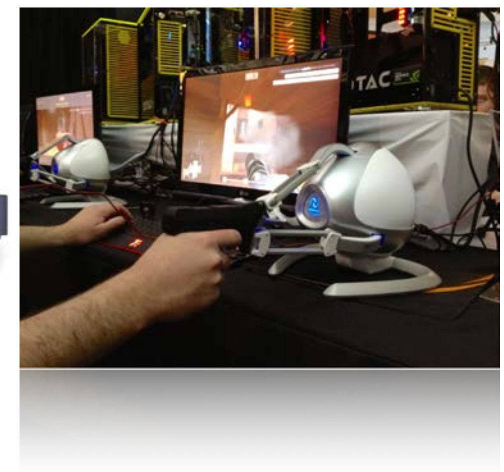
Enables physical interaction with virtual (or remotely located) objects



Applications

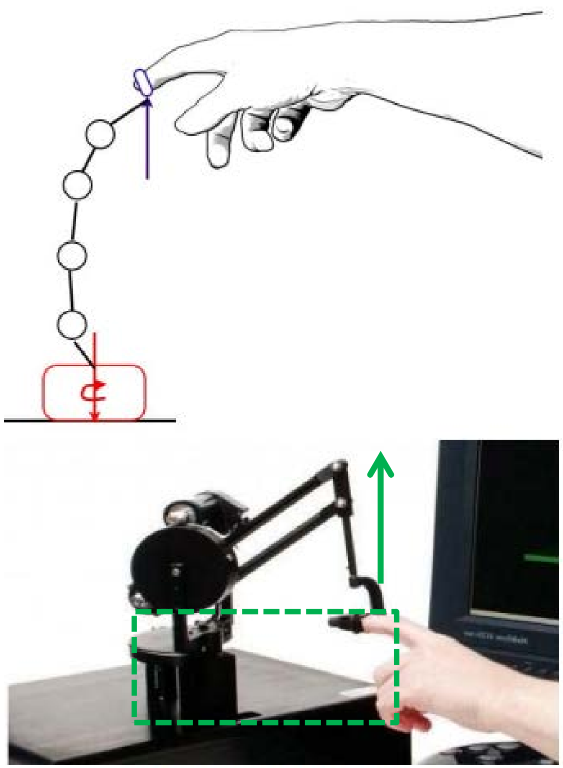
3D Design & Modelling

Medical



Entertainment

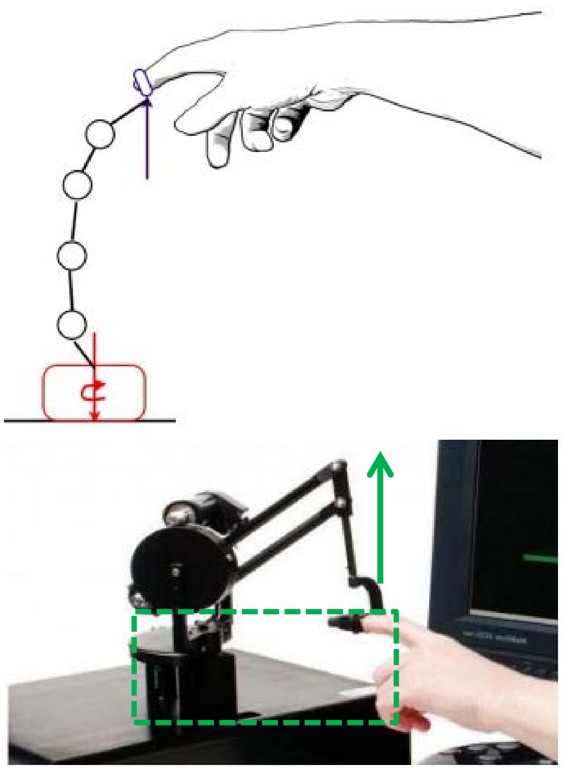
From grounded to wearable haptics



(a) Grounded haptics
(e.g., Phantom Premium)

C. Pacchierotti, S. Sinclair, M. Solazzi, A. Frisoli, V. Hayward, D. Prattichizzo. "Wearable haptic systems for the fingertip and the hand: taxonomy, review, and perspectives" IEEE Transactions on Haptics, 10(4):580-600, 2017.

From grounded to wearable haptics



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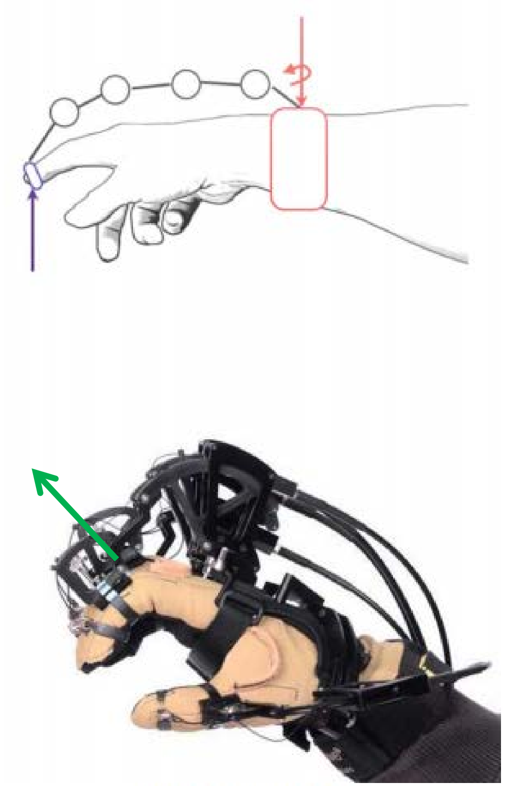

(b) Exoskeletons
(e.g., CyberGrasp)

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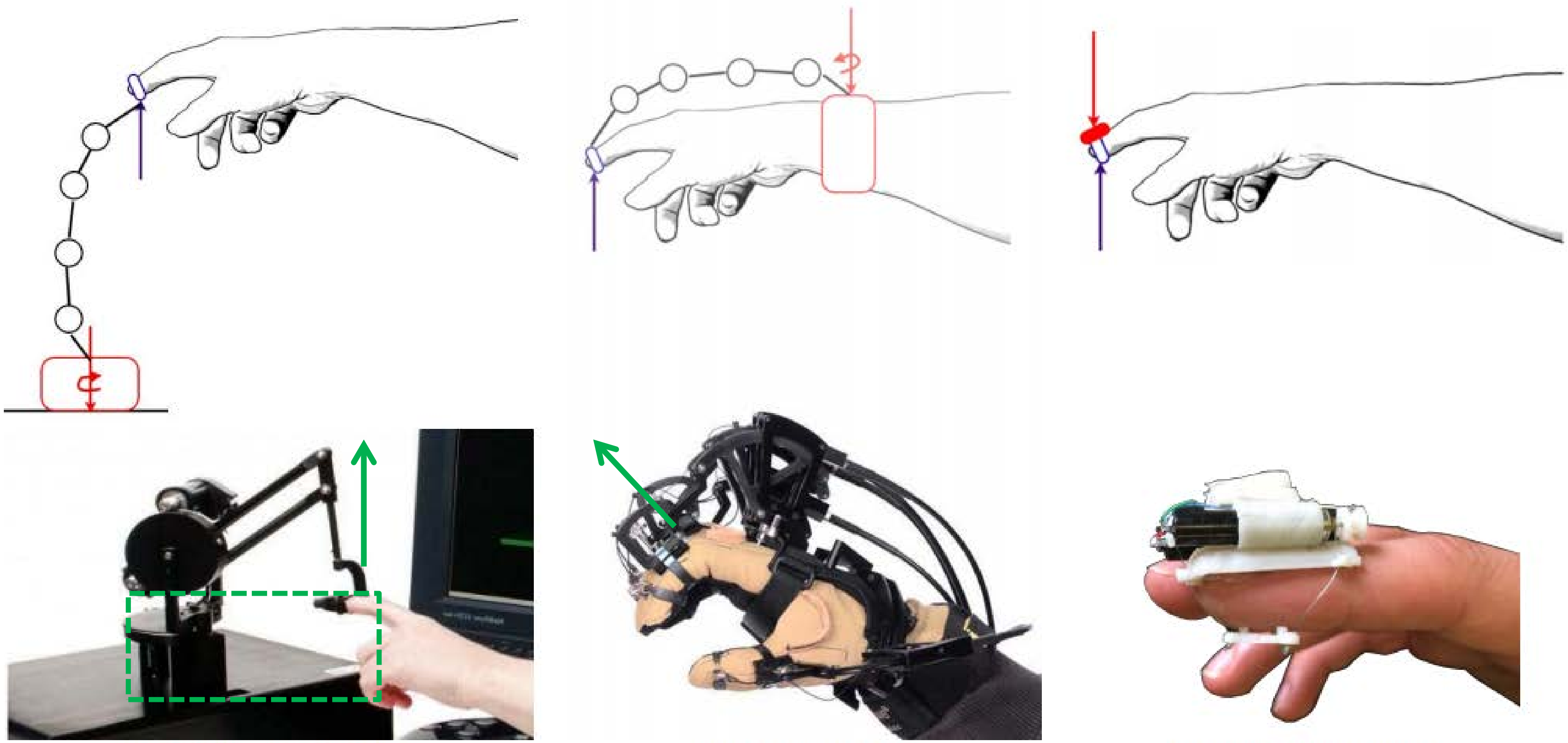
From grounded to wearable haptics



(a) Grounded haptics (e.g., Phantom Premium) (b) Exoskeletons (e.g., CyberGrasp) (c) Fingertip devices (e.g., 3-DoF cable-driven device [5])

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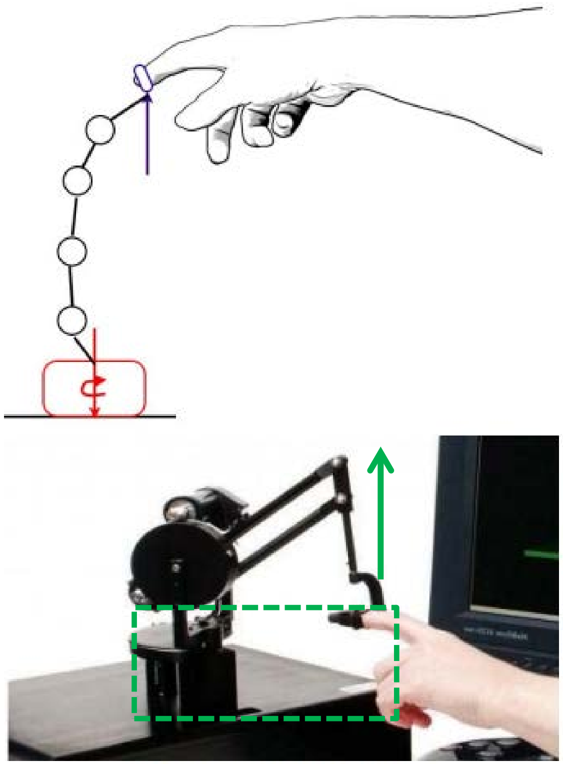

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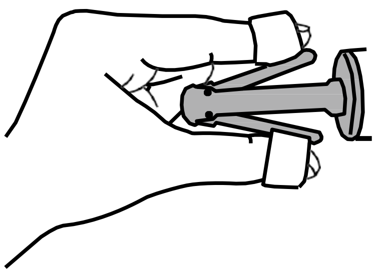
Kinesthetic grounded devices

manipulandum

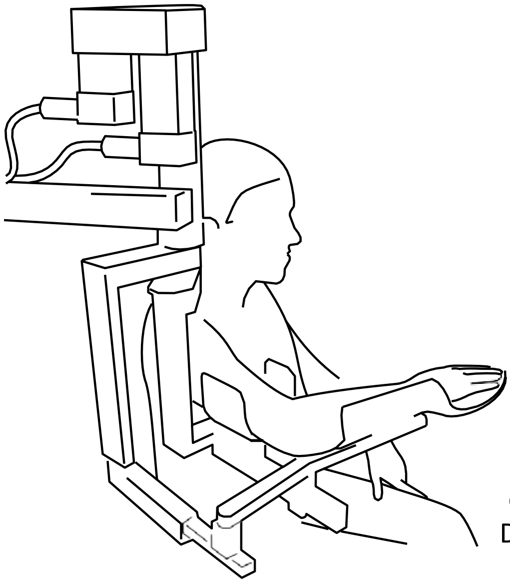
drawing by Jorge Cham

grasp



drawing by Tricia Gibo

exoskeleton



drawing by
David Grow

Slide from Allison Okamura

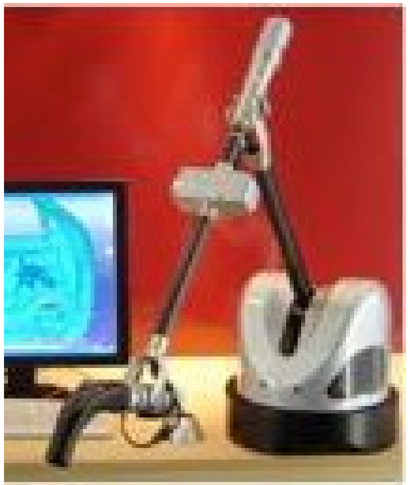
Manipulandum devices (expensive)

Omega
from Force Dimension

delta configuration
3 degrees of freedom

Phantom Premium 1.5
from SensAble/Geomagic

5-bar + rotation
3 degrees of freedom



Virtuose from
Haption

additional “wrist”
6 degrees of freedom

Manipulandum devices (expensive)

Xitact IHP

Sigma.7
(Force Dimension)

Delta (Force Dimension)

Example of use in robotic teleoperation

(courtesy of Force Dimension)

Example of use in robotic teleoperation

(from YouTube, channel Kinova Robotics)

Example of use in Virtual Reality

(from YouTube, IRISA)

Manipulandum devices (cheap)

Falcon from
Novint

delta configuration 3
degrees of freedom

Phantom Omni/Touch
from SensAble/Geomagic

5-bar + rotation
3 degrees of freedom

Sidewinder
from Microsoft

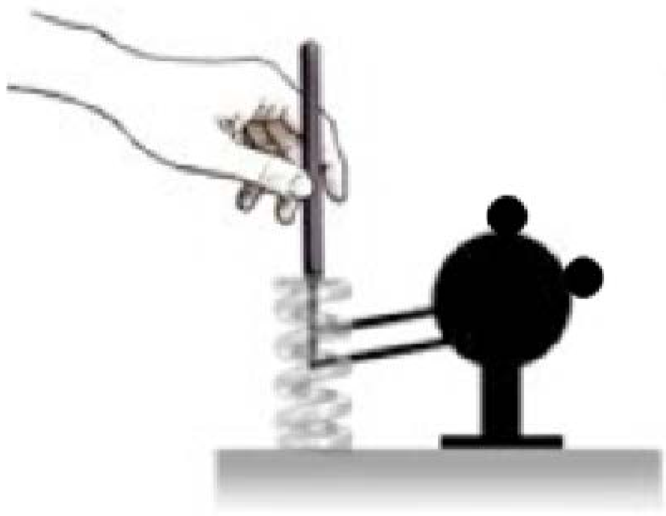
spherical mechanism
2 degrees of freedom

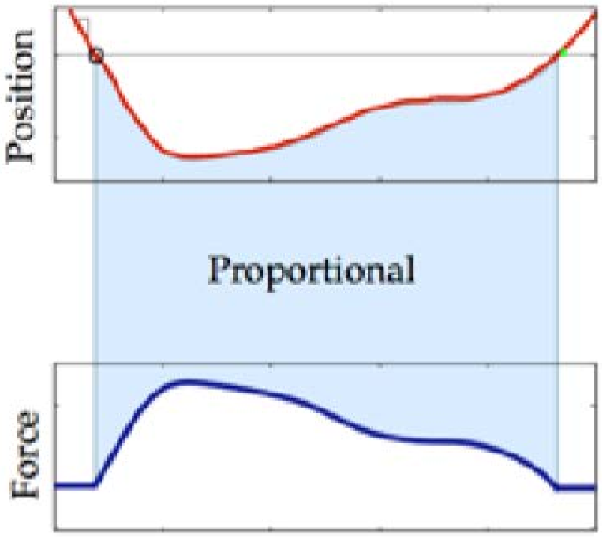
Example of use in Entertainment/Gaming

(from YouTube)

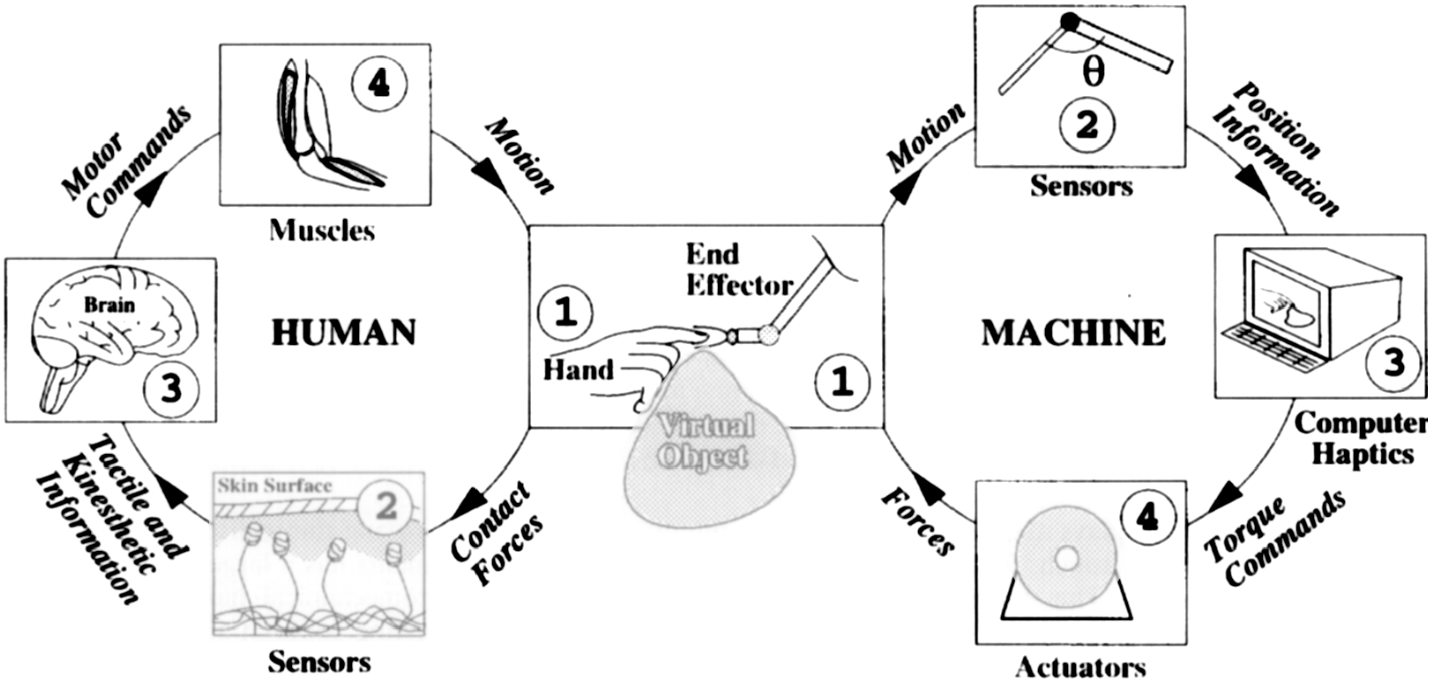
Design goals for a kinesthetic interface

- free space feels free
- virtual objects feel like real objects
- large forces (need strong actuators)
- forces change quickly (high bandwidth)
- sufficiently large workspace



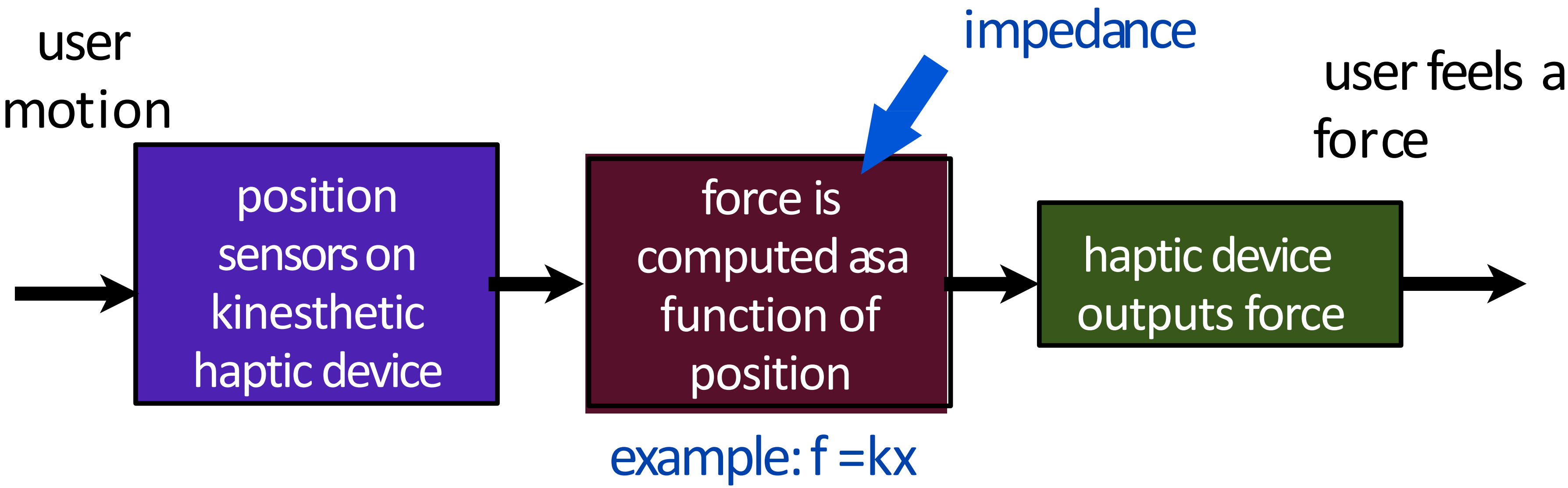


Information & Power Flows



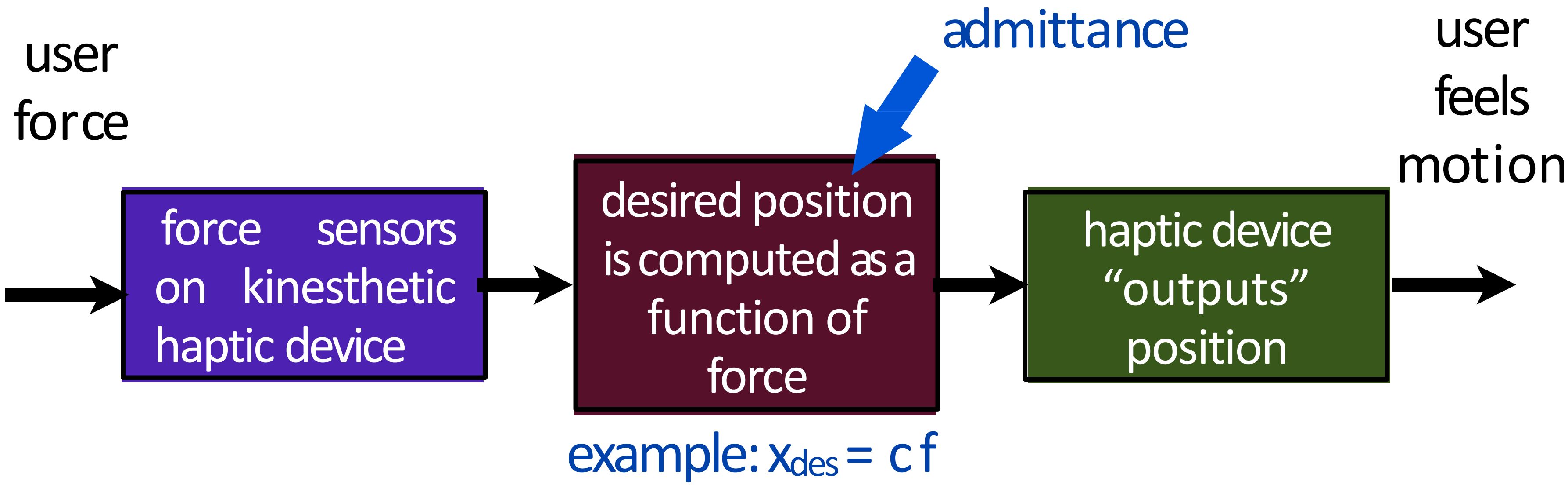
[From M. Srinivasan and C. Basdogan, *Computers & Graphics* 21(4), 1997.]

Impedance-type kinesthetic devices

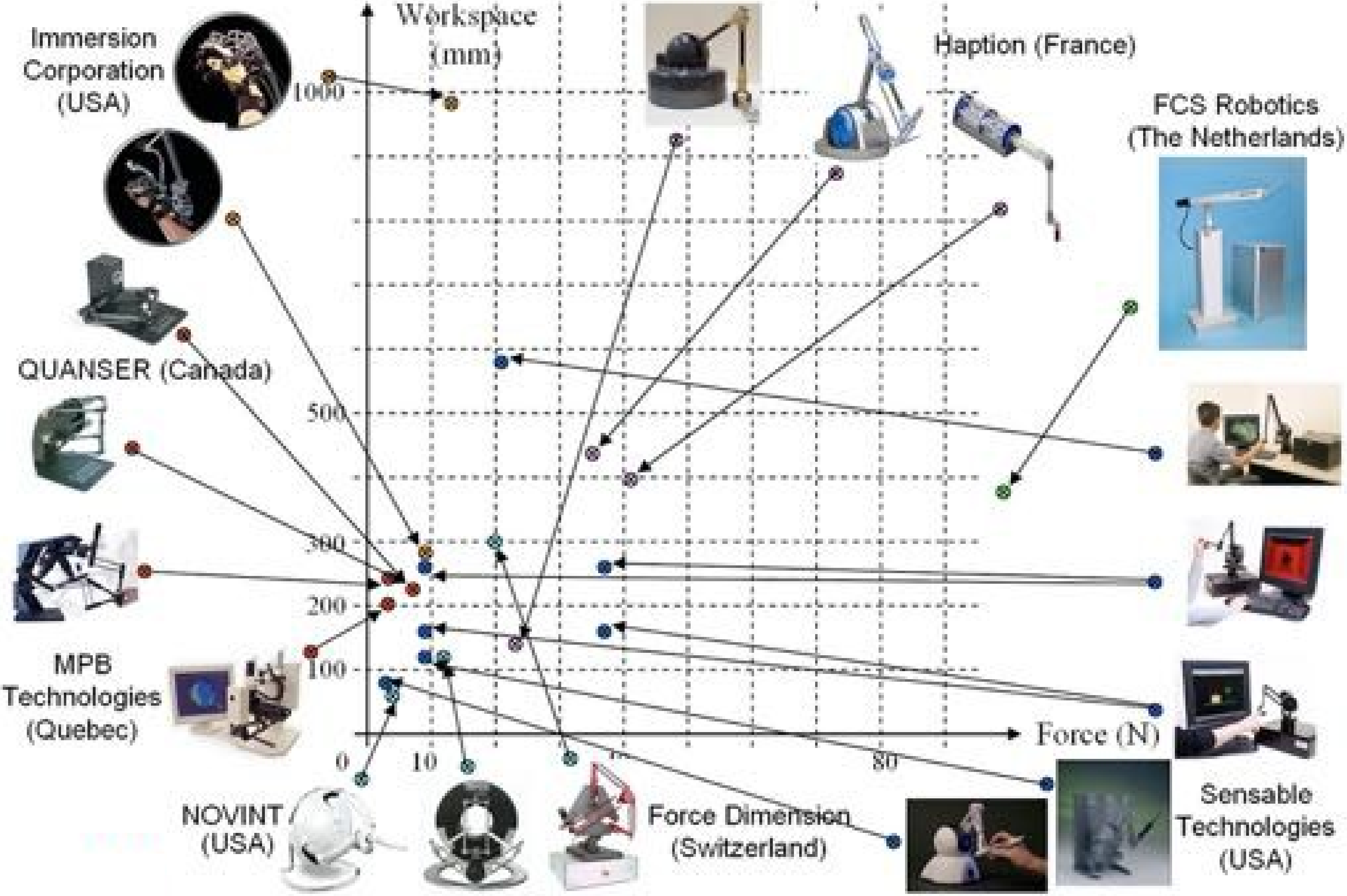


most force feedback devices are of the "impedance" type

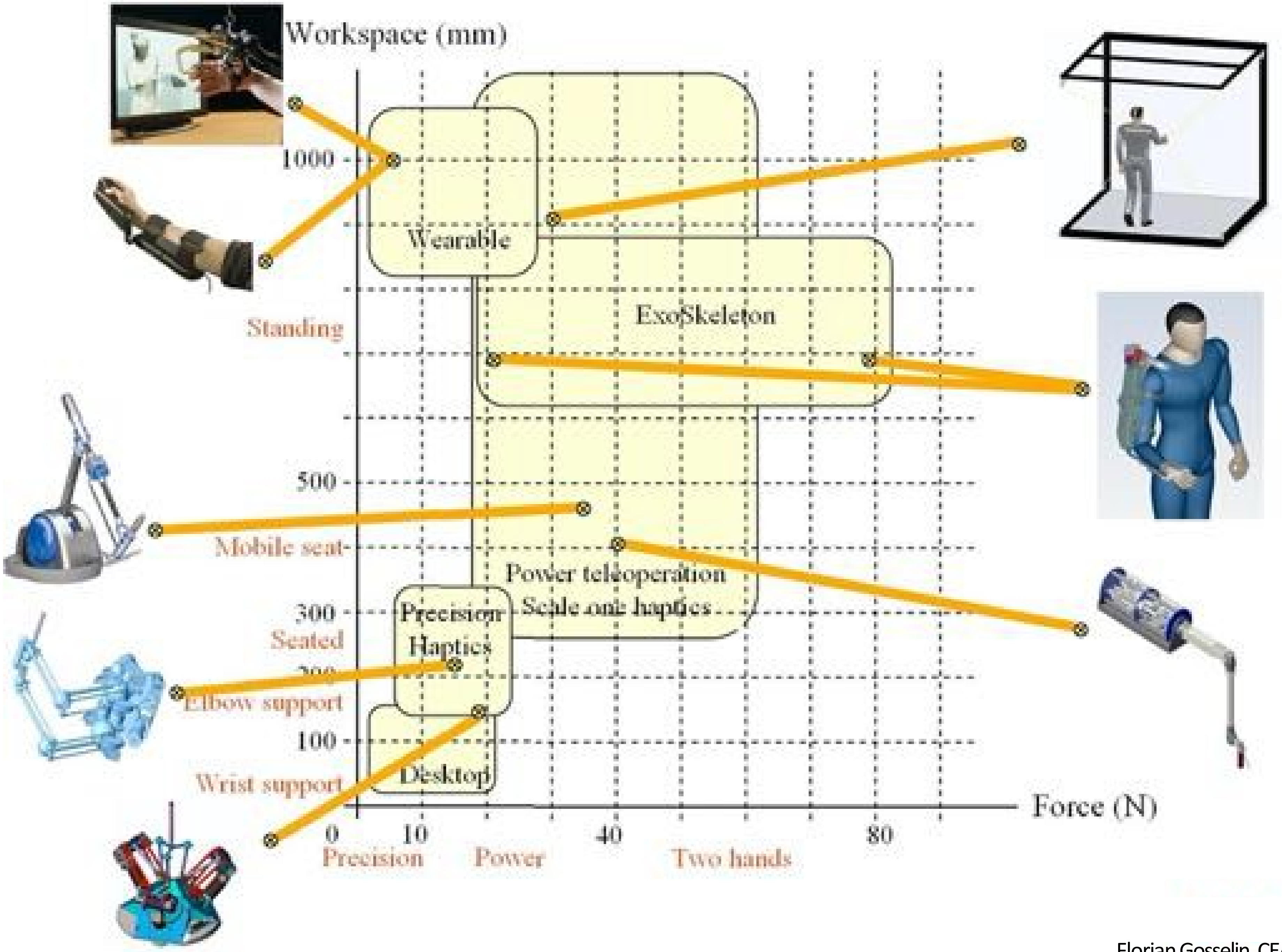
Admittance-type kinesthetic devices



"admittance"-type devices are not as common



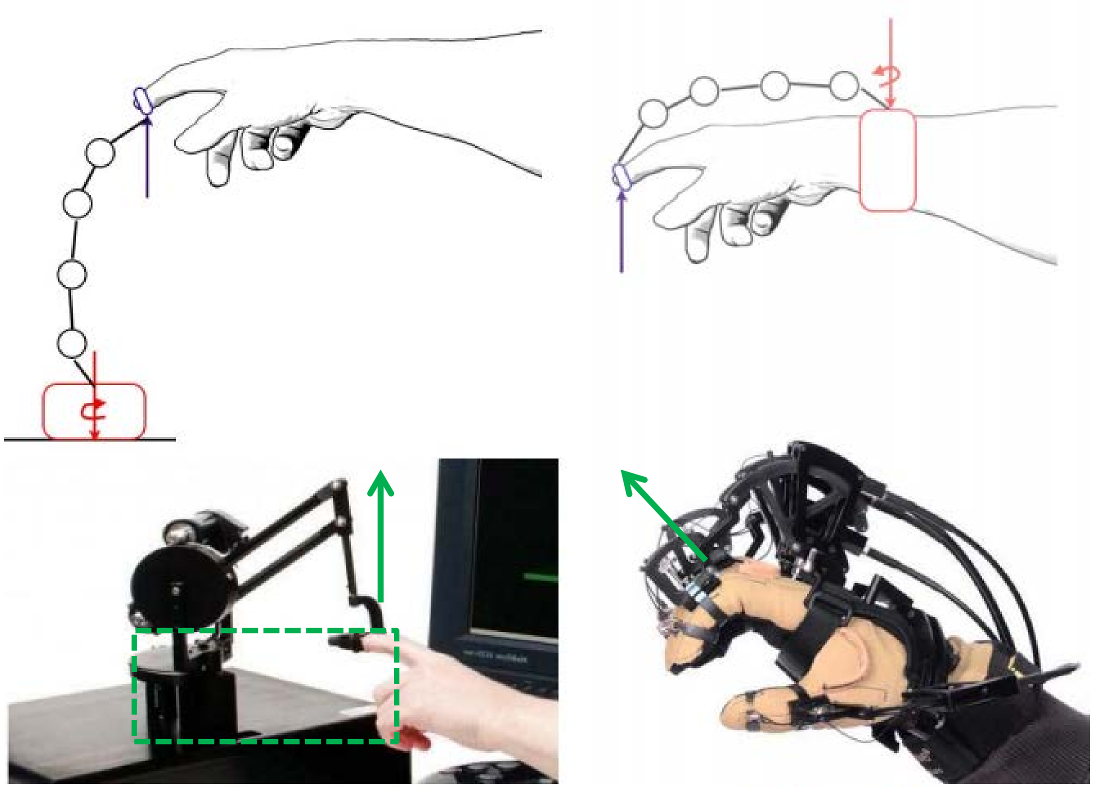
Florian Gosselin, CEA



Florian Gosselin, CEA

Questions?

From grounded to wearable haptics



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(e.g., Phantom Premium)

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Grip/grasp devices

Custom haptic gripper for Phantom Premium

Single-finger Cybergrasp from Cyberglove Systems

da Vinci Surgical System from Intuitive Surgical, Inc. (no programmable force feedback on gripper)

Exoskeletons

KINARM Exoskeleton
from BKIN Technologies

Harvard

DARPA

Example of use in Entertainment/Gaming

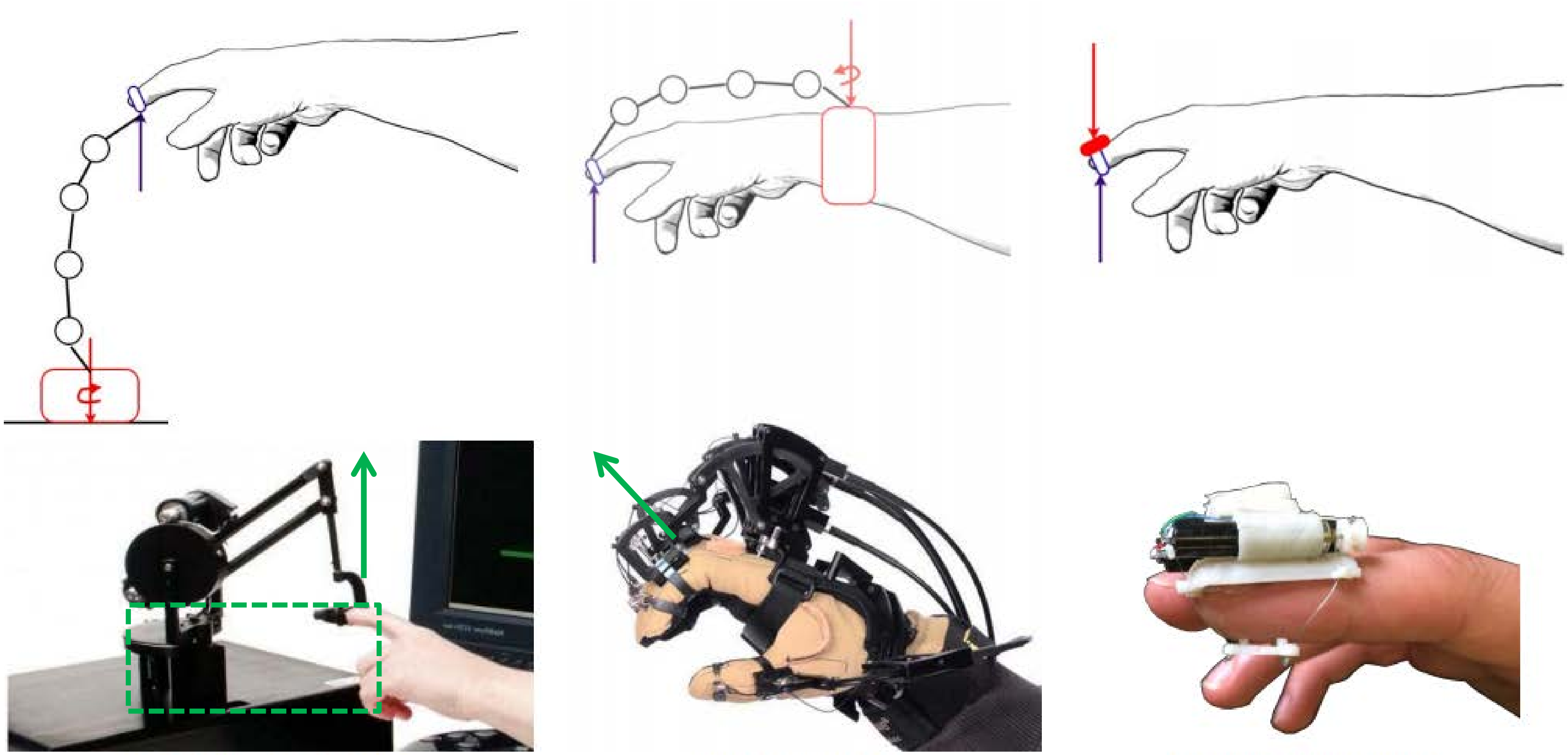
(from YouTube, channel SenseGlove)

Characterization of Force/Position Haptic Devices

- Degrees of freedom: number of joints
- Active versus passive: force reflecting or not
- Grounding: grounded vs. exo-skeletal (worn on body)
- Sensing quality: resolution, maximum and range
- Actuator quality: resolution, maximum and range
- Bandwidth

Questions?

From grounded to wearable haptics



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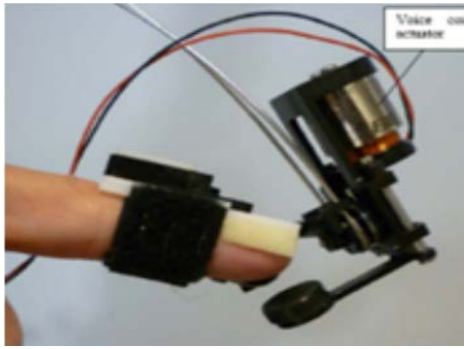
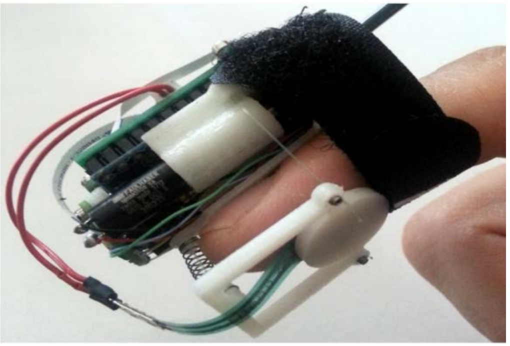
Wearable devices for the fingertips

- Many groups have focused their attention on wearable finger devices, since it is the part of the body most often used for grasping and manipulation.
- VR and AR are promising applications for wearable haptics.
- The gaming business will power more than **$128 billion** in 2020 (+10% w.r.t. 2016);



Solazzi et al. 2011



Pacchierotti et al. 2014

Schorr and Okamura, 2017

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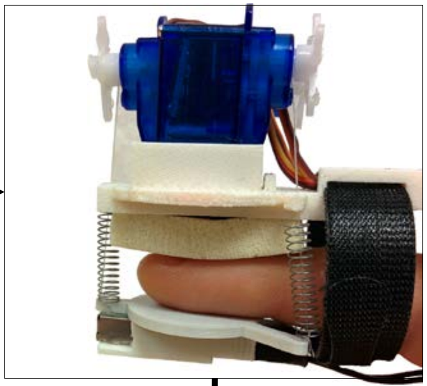
Wearable haptics for the fingertip

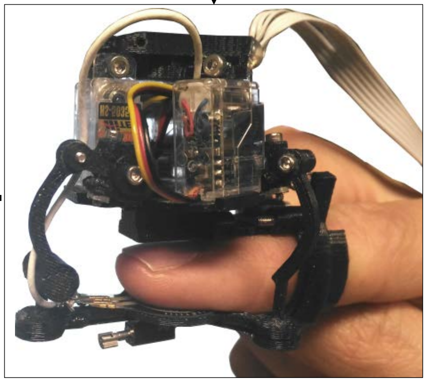
(Prattichizzo et al., ToH 2013)

ISSUE: it was not possible to release the platform, which was always contacting the finger skin

(Pacchierotti et al., IJRR 2015 and TBME 2016)

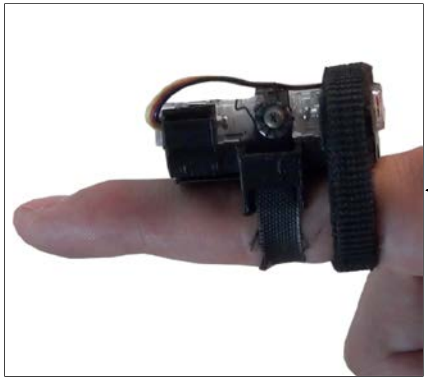


ISSUE: using three cables made not possible to precisely control the platform motion



(Chinello et al., ToH 2017 and TIE 2019)

ISSUE: wearing these devices at your fingertip impairs any interaction with the real environment

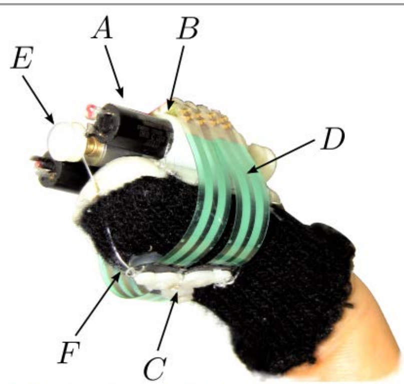


(Pacchierotti et al., HAPTICS 2016; De Tinguy et al., VR 2018)

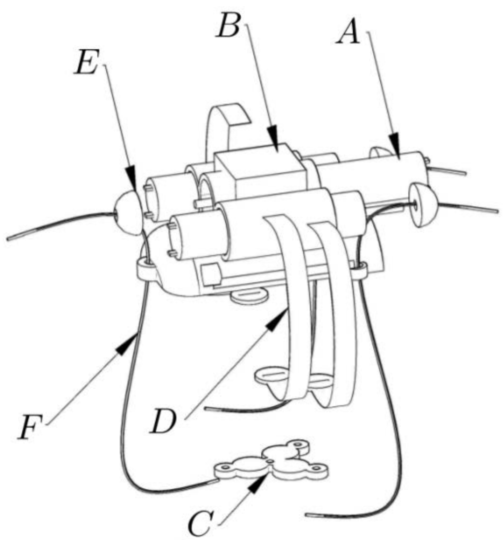
Wearable haptics for the fingertip

(Prattichizzo et al., ToH 2013)

3-DoF wearable device with cables



(a) Prototype worn on the index finger.



(b) Computer-aided design (CAD) sketch.

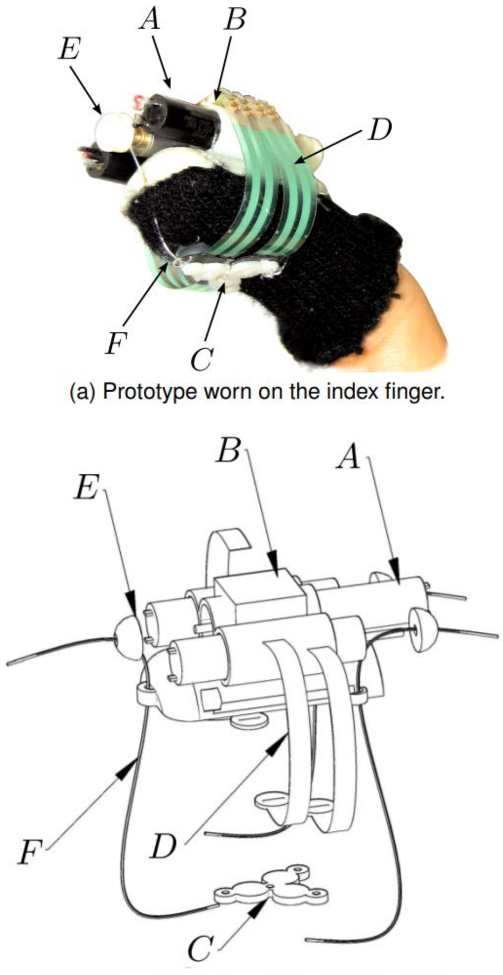
(B) static platform grounded to the fingernail,
(A, E) three DC motors with their pulleys,
(C) end-effector, a mobile platform on the fingertip,
(F) three wires connecting the motors to the end-effector,
(D) thee FSR sensors are placed on the mobile platform.

The actuators we used are three 0615S Faulhaber motors.

The mobile platform has a Y shape and allows simulation of contact interaction with slanted surfaces.

D. Prattichizzo, F. Chinello, C. Pacchierotti, M. Malvezzi. “Towards wearability in fingertip haptics: a 3-DoF wearable device for cutaneous force feedback.” IEEE Transactions on Haptics, 6(4):506-516, 2013.

3-DoF wearable device with cables



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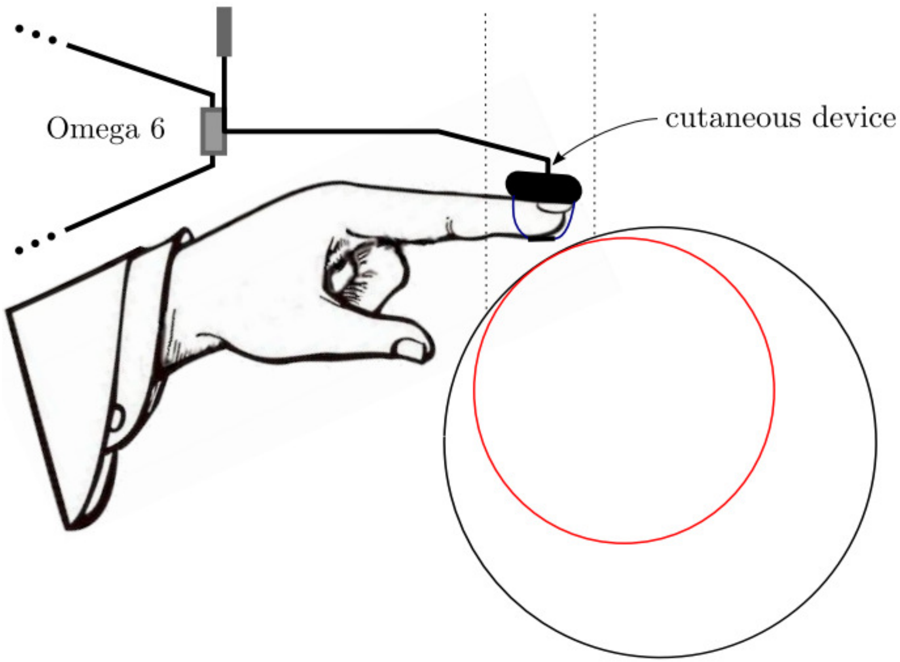

JND for H condition (wearable+grounded): 2.22 ± 0.29 m^{-1}
JND for K condition (grounded only): 2.56 ± 0.36 m^{-1}

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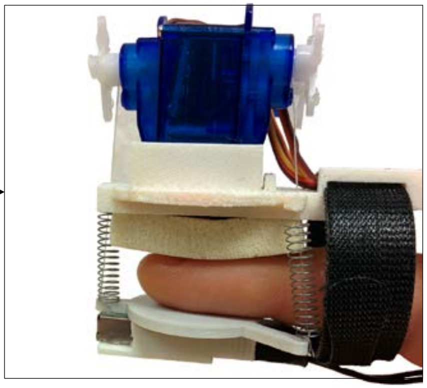
Wearable haptics for the fingertip

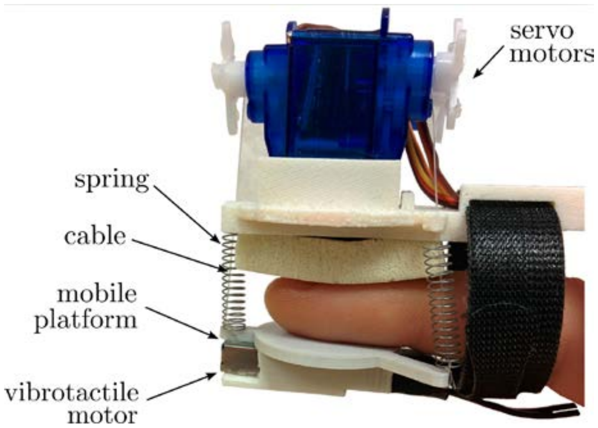
(Prattichizzo et al., ToH 2013)

ISSUE: it was not possible to release the platform, which was always contacting the finger skin



(Pacchierotti et al., IJRR 2015 and TBME 2016)

3-DoF wearable device with cables and springs



C. Pacchierotti, L. Meli, F. Chinello, M. Malvezzi, D. Prattichizzo. Cutaneous haptic feedback to ensure the stability of robotic teleoperation systems. International Journal of Robotics Research, 34(14):1773-1787, 2015.
C. Pacchierotti, D. Prattichizzo, K. J. Kuchenbecker. “Cutaneous feedback of fingertip deformation and vibration for palpation in robotic surgery.” IEEE TBME, 63(2):278-287, 2016.

3-DoF wearable device with cables and springs

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3-DoF wearable device with cables and springs

S. Scheggi, L. Meli, C. Pacchierotti, D. Prattichizzo. "Touch the virtual reality: using the Leap Motion controller for hand tracking and wearable tactile devices for immersive haptic rendering." In Proc. SIGGRAPH posters, 2015.

Wearable haptics for the fingertip

(Prattichizzo et al., ToH 2013)

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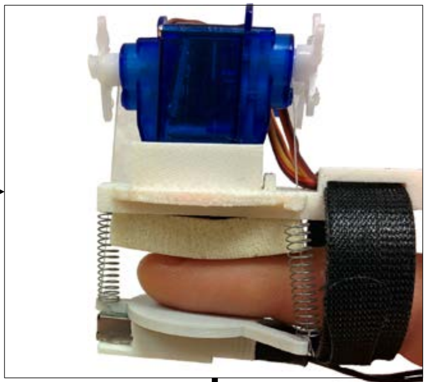

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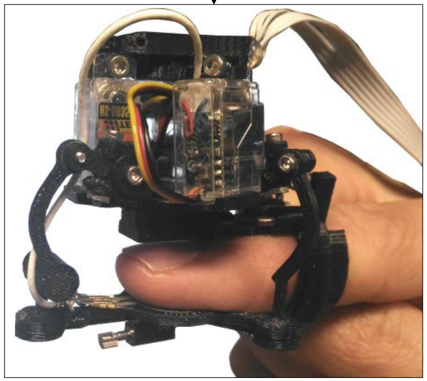
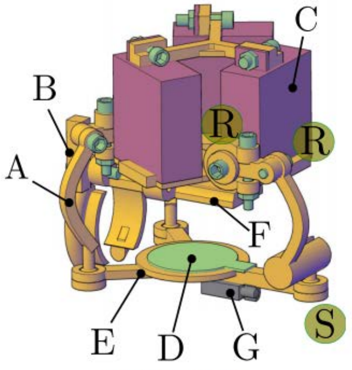
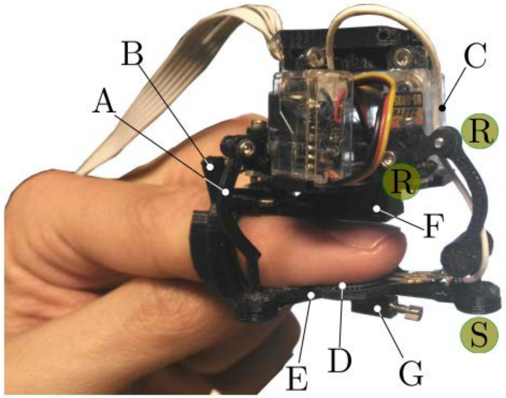


(Chinello et al., ToH 2017 and TIE 2019)

3RRS wearable device with rigid legs



(a) CAD sketch.



(b) Prototype.

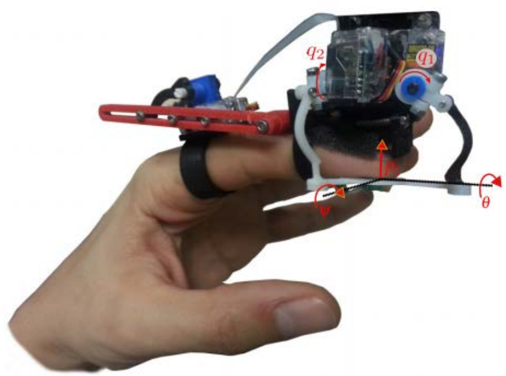
(F) static upper body, grounded on the nail
(E) mobile platform,
(C) three servo motors,
(A) three legs, connecting the mobile platform with the static body. Each leg is composed of two rigid links connected to each other and then with the body and the mobile platform, according to a Revolute-Revolute-Spherical kinematic chain,
(D) piezoresistive sensor,
(G) vibrotactile motor, attached below the platform,
(B) clamp to easily wear the device on the finger.

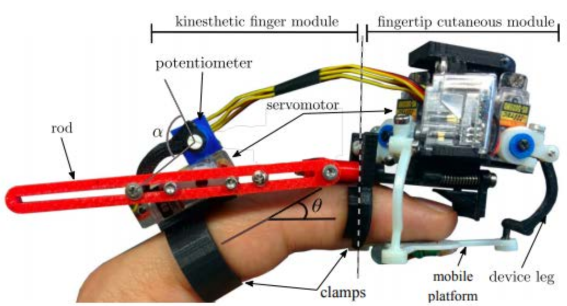
We used three HS-5035HD servomotors (HiTech Motors) and one 304-101 vibration motor (Precision Microdrives)

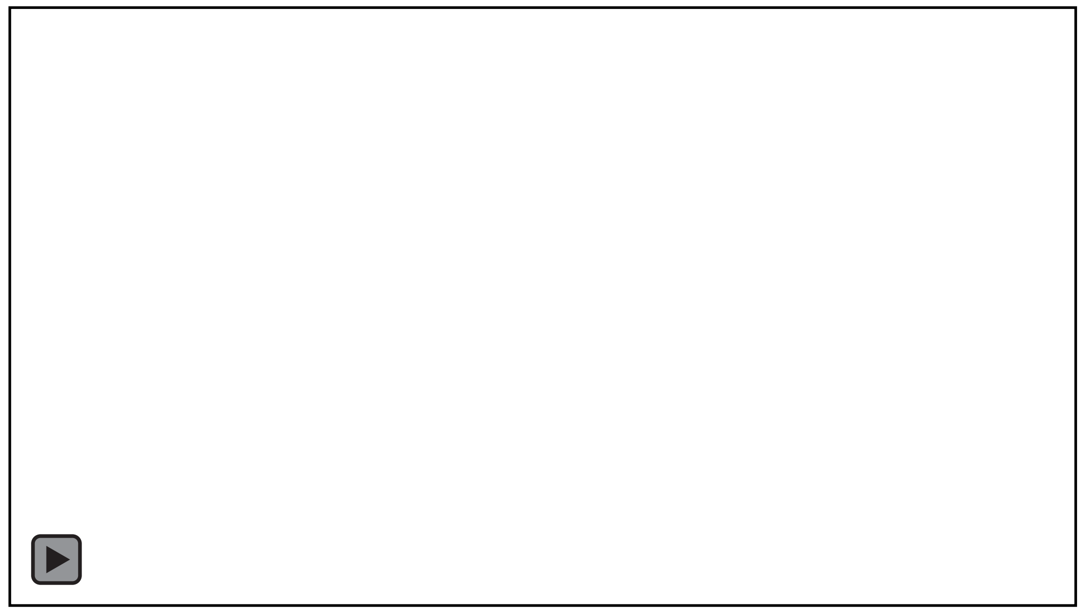
F. Chinello, M. Malvezzi, D. Prattichizzo, C. Pacchierotti. "A modular wearable finger interface for cutaneous and kinesthetic interaction: control and evaluation." IEEE Trans. on Industrial Electronics, To appear, 2019.
F. Chinello, C. Pacchierotti, M. Malvezzi, D. Prattichizzo. "A Three Revolute-Revolute-Spherical wearable fingertip cutaneous device for stiffness rendering." IEEE Transactions on Haptics, 11(1):39-50, 2018.

3RRS wearable device + kinesthetic finger exoskeleton

This device can be also coupled with a kinesthetic finger exoskeleton.



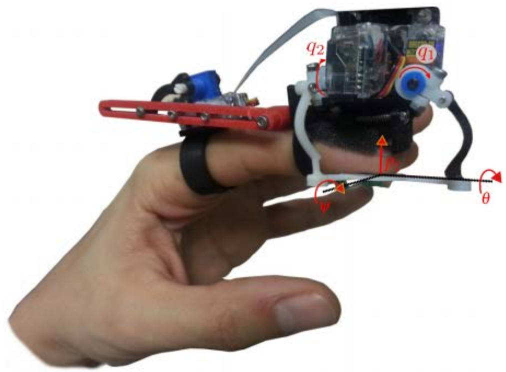


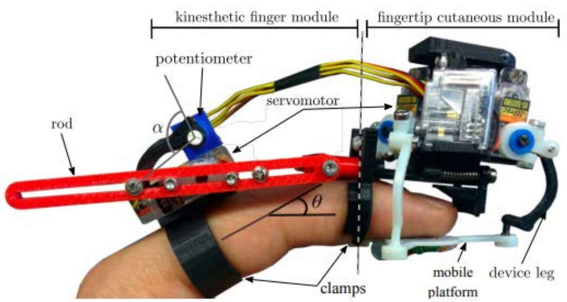


F. Chinello, M. Malvezzi, D. Prattichizzo, C. Pacchierotti. "A modular wearable finger interface for cutaneous and kinesthetic interaction: control and evaluation." IEEE Trans. on Industrial Electronics, To appear, 2019.

3RRS wearable device: curvature discrimination

We used the same-different procedure to evaluate the differential curvature threshold for this device.





JND for condition H (fingertip+exos): 2.41 ± 0.11 m^{-1}
JND for condition K (exoskeleton only): 3.00 ± 0.16 m^{-1}

F. Chinello, M. Malvezzi, D. Prattichizzo, C. Pacchierotti. “A modular wearable finger interface for cutaneous and kinesthetic interaction: control and evaluation.” IEEE Trans. on Industrial Electronics, To appear, 2019.

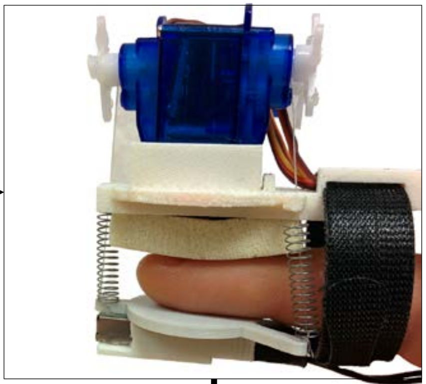
3RRS wearable device: palpation experiment

F. Chinello, M. Malvezzi, D. Prattichizzo, C. Pacchierotti. “A modular wearable finger interface for cutaneous and kinesthetic interaction: control and evaluation.” IEEE Trans. on Industrial Electronics, To appear, 2019.

Wearable haptics for the fingertip

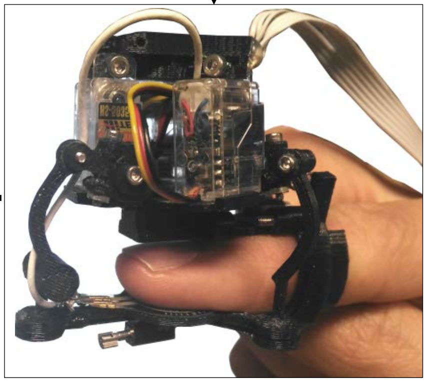
(Prattichizzo et al., ToH 2013)

ISSUE: it was not possible to release the platform, which was always contacting the finger skin



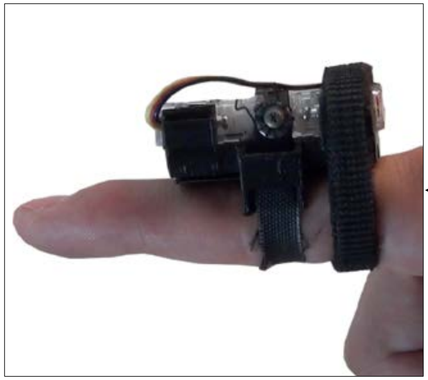
(Pacchierotti et al., IJRR 2015 and TBME 2016)

ISSUE: using three cables made not possible to precisely control the platform motion



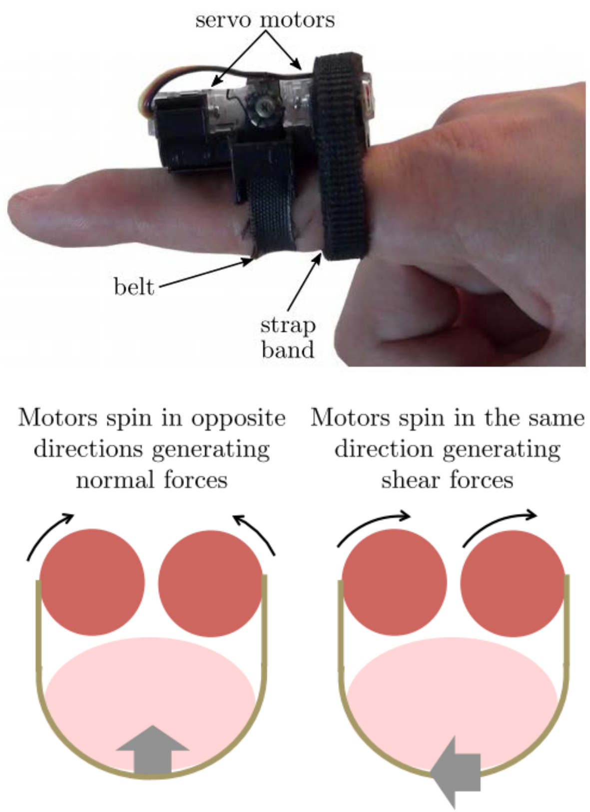
(Chinello et al., ToH 2017 and TIE 2019)

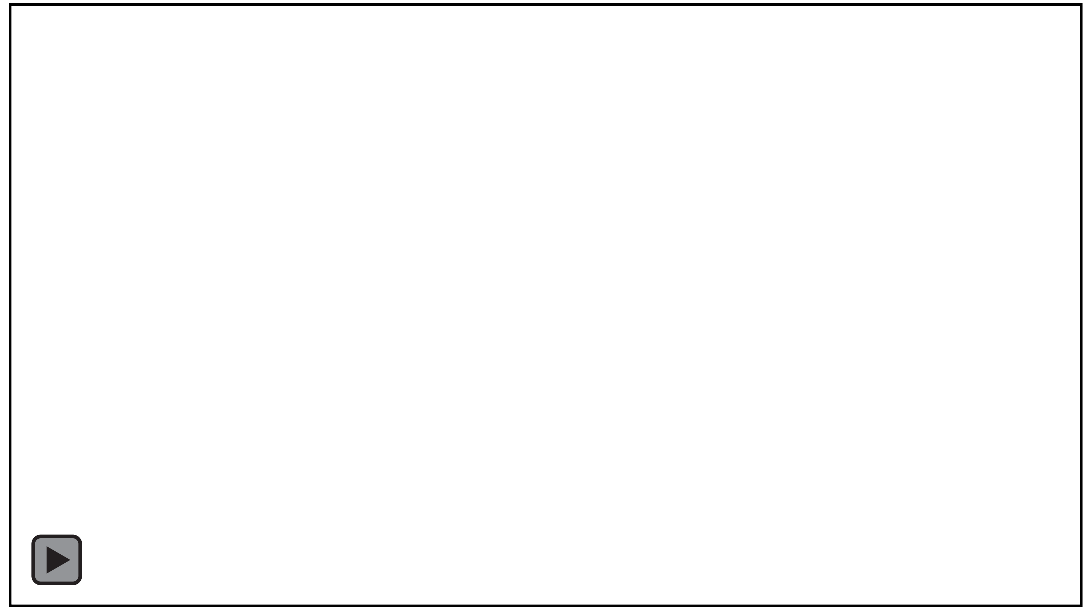
ISSUE: wearing these devices at your fingertip impairs any interaction with the real environment



(Pacchierotti et al., HAPTICS 2016; De Tinguy et al., VR 2018)

2-DoF wearable device for the proximal phalanx





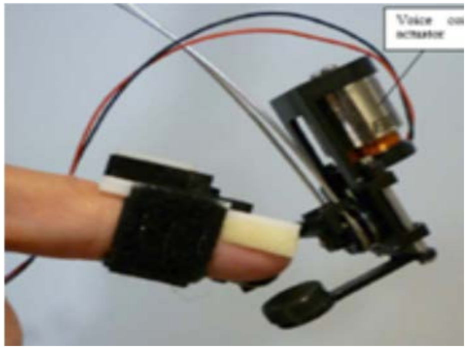
C. Pacchierotti, G. Salvietti, I. Hussain, L. Meli, D. Prattichizzo. “The hRing: a wearable haptic device to avoid occlusions in hand tracking.” In Proc. IEEE Haptics Symposium (HAPTICS), Pages 134-139, Philadelphia, PA, USA, 2016.
X. De Tinguy, C. Pacchierotti, M. Marchal, A. Lecuyer. “Enhancing the Stiffness Perception of Tangible Objects in Mixed Reality Using Wearable Haptics.” In Proc. IEEE Virtual Reality , Reutlingen, Germany, March 2018.

Example of use in AR

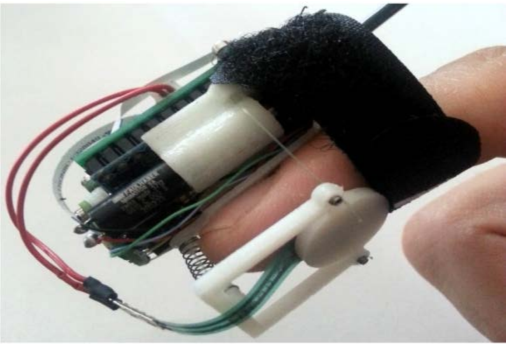
M. Maisto, C. Pacchierotti, F. Chinello, G. Salvietti, A. De Luca, D. Prattichizzo. Evaluation of wearable haptic systems for the fingers in Augmented Reality applications. IEEE Transactions on Haptics, 2017.

Other types of tactile devices

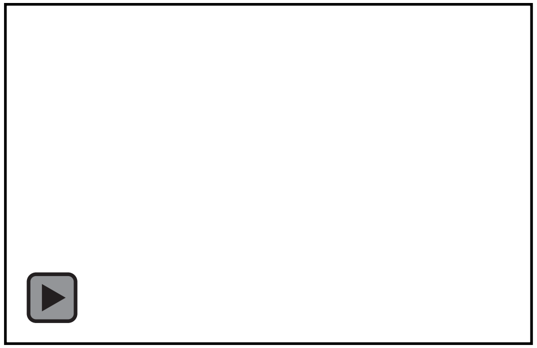
- Many groups have focused their attention on wearable finger devices, since it is the part of the body most often used for grasping and manipulation.
- VR and AR are promising applications for wearable haptics.
- The gaming business will power more than **$128 billion** in 2020 (+10% w.r.t. 2016);



Solazzi et al. 2011



Pacchierotti et al. 2014



Schorr and Okamura, 2017

C. Pacchierotti, S. Sinclair, M. Solazzi, A. Frisoli, V. Hayward, D. Prattichizzo. "Wearable haptic systems for the fingertip and the hand: taxonomy, review, and perspectives" IEEE Transactions on Haptics, 10(4):580-600, 2017.

Other types of tactile devices

IEEE TRANSACTIONS ON HAPTICS, VOL. XX, NO. X, XX 20XX 1

Wearable Haptic Systems for the Fingertip and the Hand: Taxonomy, Review, and Perspectives

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Massimiliano Solazzi, *Member, IEEE*, Antonio Frisoli, *Member, IEEE*,
Vincent Hayward, *Fellow, IEEE*, Domenico Prattichizzo, *Fellow, IEEE*

Abstract—In the last decade, we have witnessed a drastic change in the form factor of audio and vision technologies, from heavy and grounded machines to lightweight devices that naturally fit our bodies. However, only recently, haptic systems have started to be designed with wearability in mind. The wearability of haptic systems enables novel forms of communication, cooperation, and integration between humans and machines. Wearable haptic interfaces are capable of communicating with the human wearers during their interaction with the environment they share, in a natural and yet private way. This paper presents a taxonomy and review of wearable haptic systems for the fingertip and the hand, focusing on those systems directly addressing wearability challenges. The paper also discusses the main technological and design challenges for the development of wearable haptic interfaces, and it reports on the future perspectives of the field. Finally, the paper includes two tables summarizing the characteristics and features of the most representative wearable haptic systems for the fingertip and the hand.

Index Terms—wearable haptics, fingertip haptics, hand exoskeletons, wearable devices, wearable interfaces, cutaneous force feedback, tactile force feedback, taxonomy, review

C. Pacchierotti, S. Sinclair, M. Solazzi, A. Frisoli, V. Hayward, D. Prattichizzo. "Wearable haptic systems for the fingertip and the hand: taxonomy, review, and perspectives" IEEE Transactions on Haptics, 10(4):580-600, 2017.

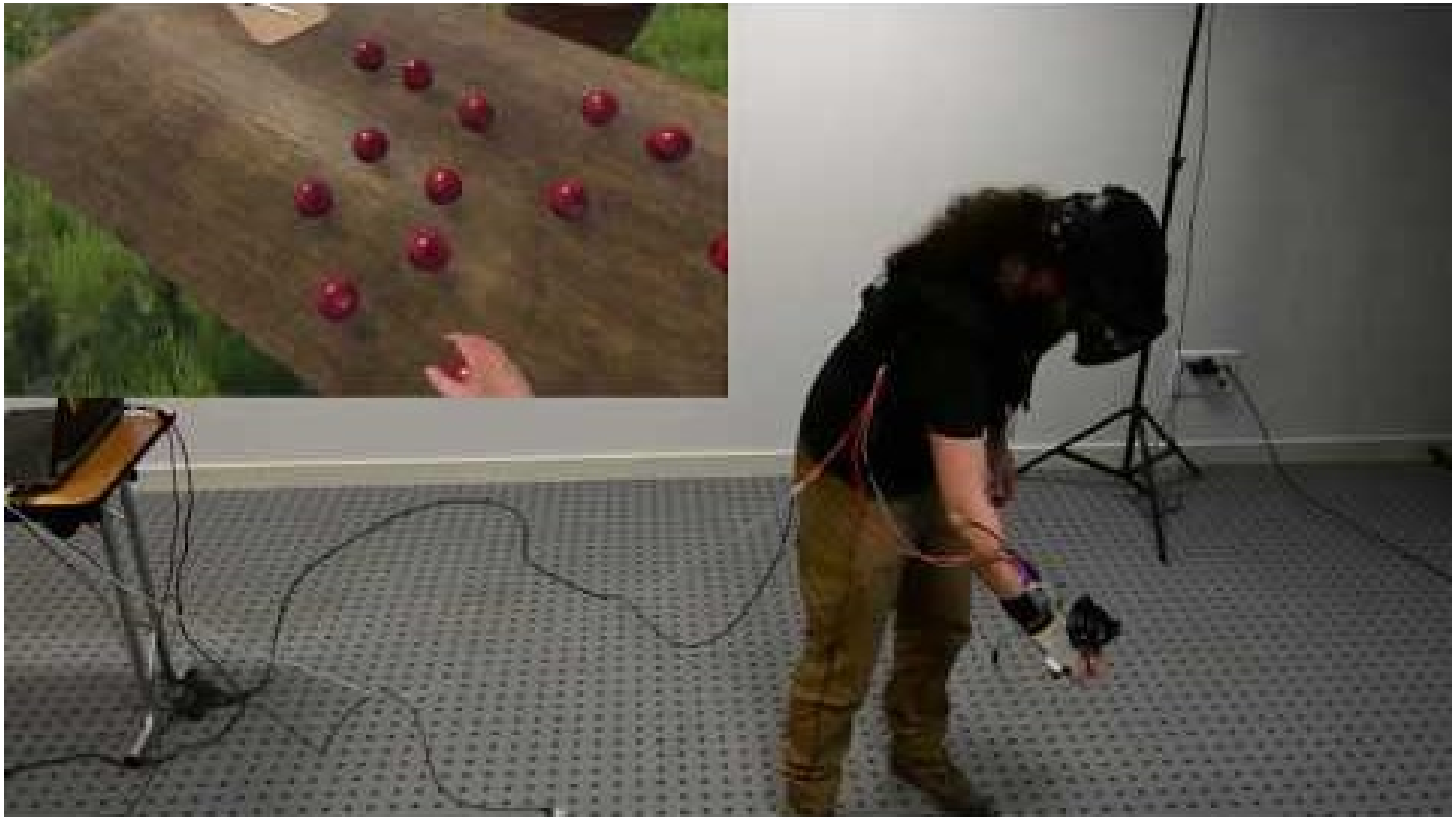
Encounter-type haptics

Encounter-type devices solve one of the main drawbacks of common haptic interfaces: their **limited transparency in free space** and their **restricted ability to render realistic transitions between free space and contact**.

Encounter-type interfaces collide with fingers/hand and display interaction forces only if a contact occurs in the virtual environment. In free space, their end-effectors are mechanically detached from the operator.

Encounter-type haptics

Encounter-type haptics



X. de Tinguy, T. Howard, C. Pacchierotti, M. Marchal, A. Lécuyer. “WeATaViX: WEarable Actuated TAngibles for VIrtual reality eXperiences”. Proc. Eurohaptics, pp.297-306, 2020.

Challenges for designing haptic interfaces

- The sense of touch is complex and comprises a wide range of sensations, constantly integrated by our brain into a coherent sensation.

➡ It is hard (impossible?) to create a haptic interface able to coherently stimulate all our haptic sense.

- People are different, they have limbs of different sizes and different perception capabilities.

➡ Current haptic interfaces are designed following a one-size-fits all approach, which does not always perform well.

- The (high) cost of haptic interfaces is often not justified by their performance and promised added value.

➡ Tactile interfaces are inexpensive, but we still need a killer app.

Challenges for designing haptic interfaces

- The sense of touch is complex and comprises a wide range of sensations, constantly integrated by our brain into a coherent sensation.

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<u>Example/experiment</u>

1. Gather a pile of napkins, tissue, or (if you can spare it!) toilet paper

2. Divide it into piles of different thickness (number of layers) that can just barely be distinguished when probing it with your fingertip.

3. Now probe the piles with a rigid tool/stylus.

It is easier, harder, or the same to distinguish the piles?

Challenges for designing haptic interfaces

- The (high) cost of haptic interfaces is often not justified by their performance and promised added value.

➡ Tactile interfaces are inexpensive, but we still need a killer app.

Where do **you** think haptics can be useful?

Challenges for designing haptic interfaces

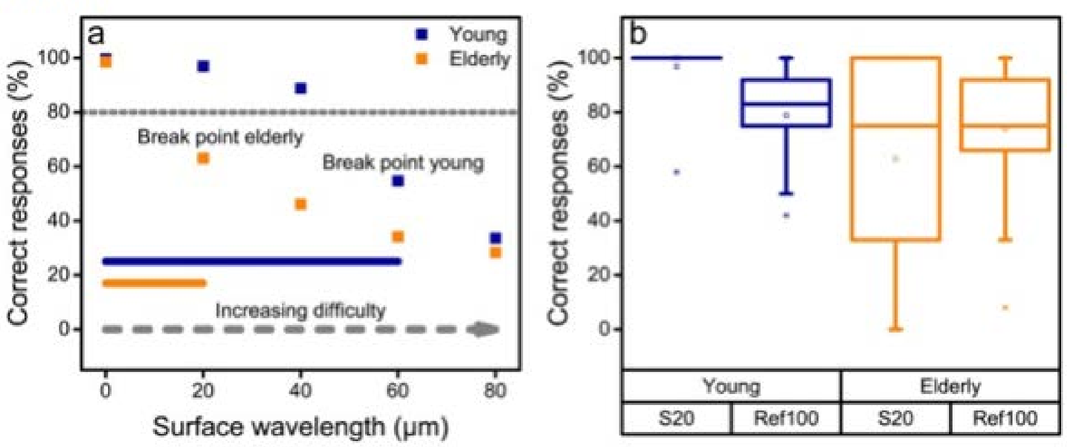
- People are different, they have limbs of different sizes and different perception capabilities.

➡ Current haptic interfaces are designed following a one-size-fits all approach, which does not always perform well.

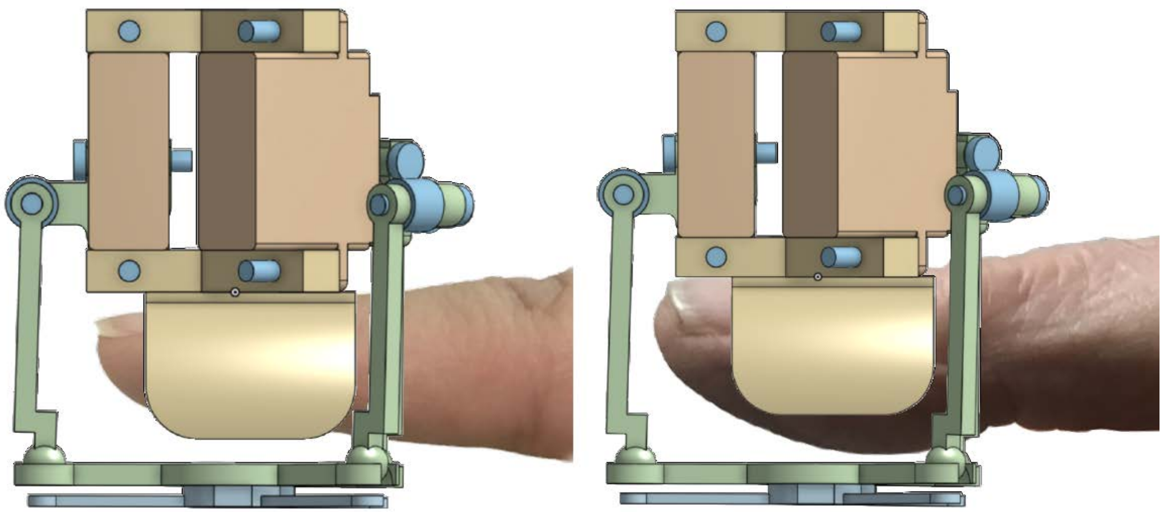
<u>Example</u>
Hearing high-frequency sounds decreases with age

What about haptics?

Figure 1



Personalizing haptic interfaces (hardware)



(a) Small fingertip wearing the device.

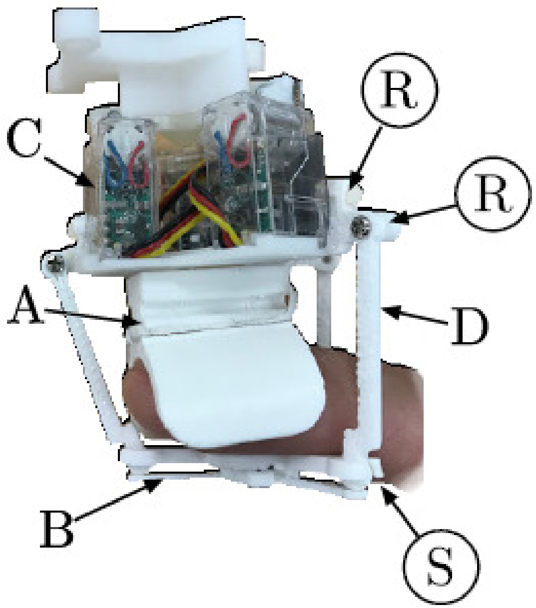
(b) Large fingertip wearing the device.

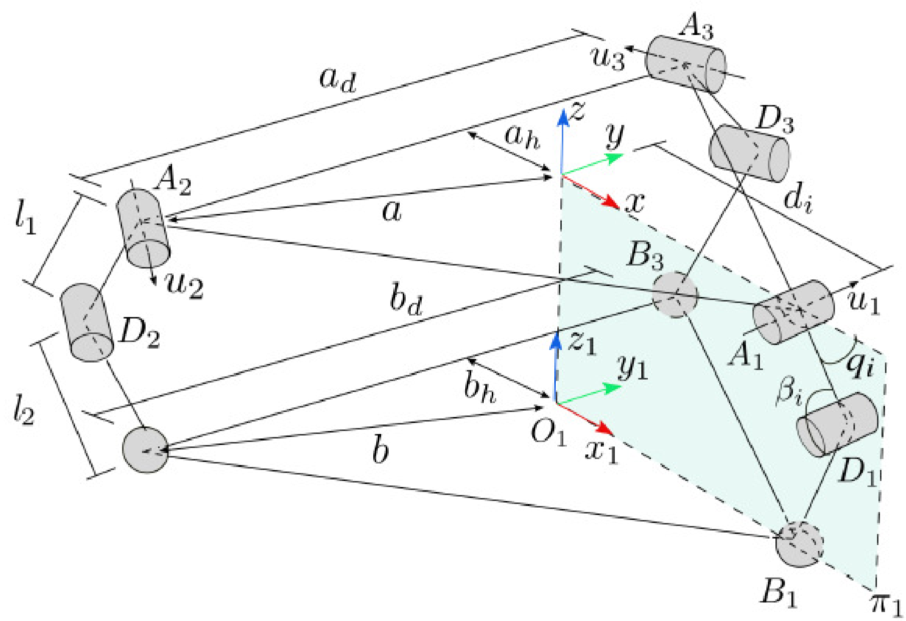
Representative problem: **the same fingertip haptic device will elicit different sensations on fingertips having different size and shape.**

Personalized haptics optimizes the device design for a target fingertip, so as to to always elicit the desired haptic sensation.

Personalizing haptic interfaces (hardware)

Let’s consider the example of this fingertip haptic device.



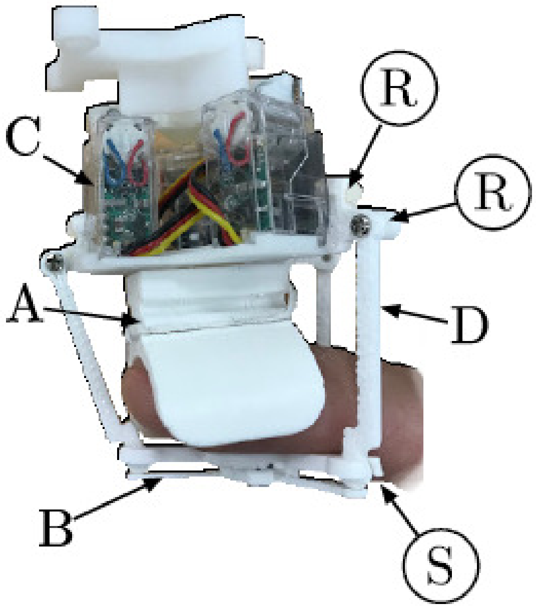


It is composed of a static upper body (A) and a mobile platform (B): the body is located above the nail, supporting three servo motors (C), while the mobile platform contacts the finger pulp. Three legs (D) connect the mobile platform with the static body.

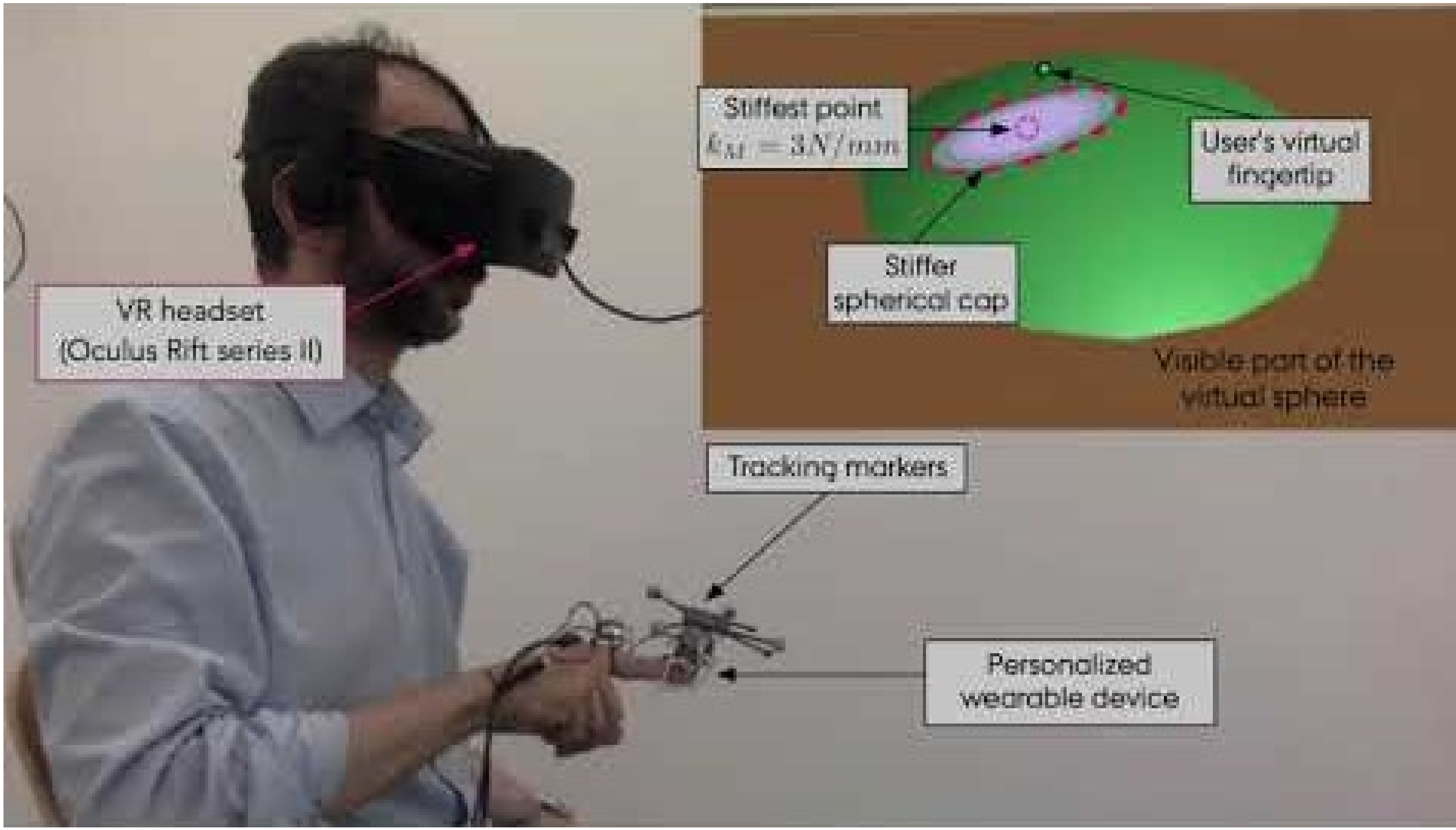
Personalizing haptic interfaces (hardware)

Malvezzi et al. (2020) came up with a system to personalize the design of this wearable tactile device for a given fingertip, considering three sub-problems in sequence:

- mobile platform (end-effector) dimensions are defined on the basis of the user's finger dimensions and the device target workspace, i.e., the surface of the finger that will be involved in the cutaneous stimulation.
- static platform dimensions are consequently defined so that, during the cutaneous stimuli application, only the mobile platform interacts with the fingertip and no undesired contacts with the legs occur.
- articulated legs lengths are defined to avoid kinematic singularities in any of the device operative configurations.



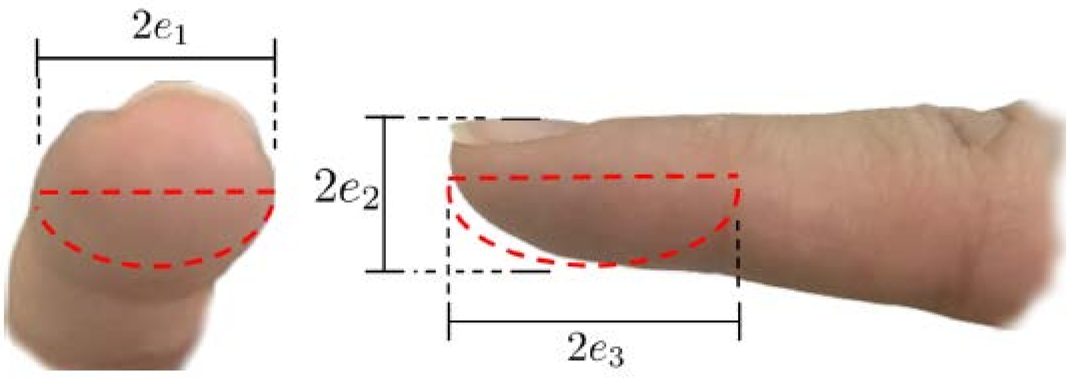
Personalizing haptic interfaces (hardware)



Rainbow

Personalizing haptic interfaces (hardware)

Let’s try!



My right index finger has

e1 = 9.5 mm; e2 = 8.5 mm; e3 = 18 mm.

Personalizing haptic interfaces (hardware)

Demonstration

Personalizing haptic interfaces (hardware)

Haptics personalization is an interesting topic that can be approached from different sides and points of view:

- Hardware/design, which is made possible by the popularization of 3d printers.
- Rendering/software (we will see it next time), where the device does not change but the haptic rendering algorithm adapts.

Personalized devices, in general, are wildly unpopular. We usually get used to the device and not the other way around.

Perspectives: non-contact/mid-air haptics

All the haptic devices we have seen contact the skin with some kind of end-effectors.

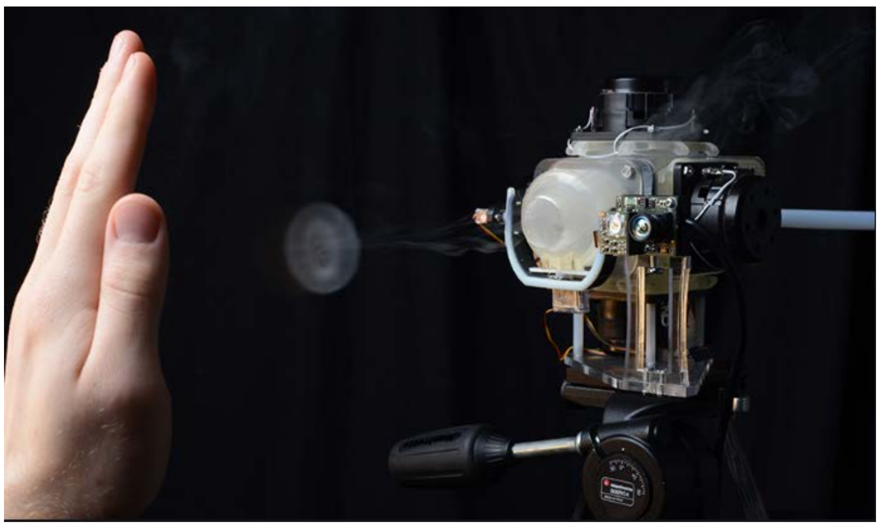
Is this necessary?

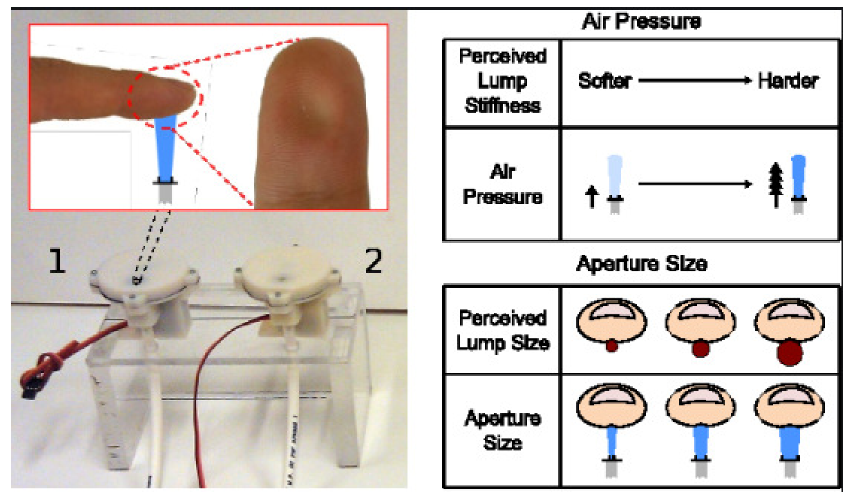
Can we elicit haptic sensations **without physically contacting the skin** with some kind of tool?

Ideas?

Perspectives: non-contact/mid-air haptics

- Air-jets haptic devices





(a) Air-Jet Lump Display (b) Control Parameters

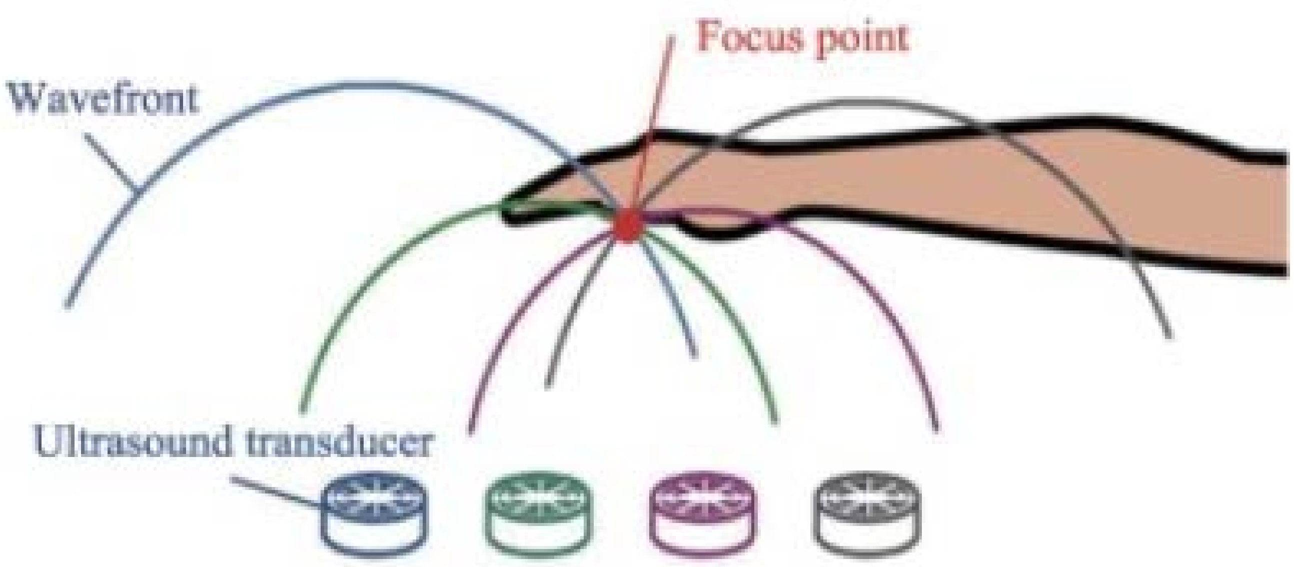
Rainbow

Perspectives: non-contact/mid-air haptics

- Magnetic haptic devices

Perspectives: non-contact/mid-air haptics

- Ultrasound haptic devices

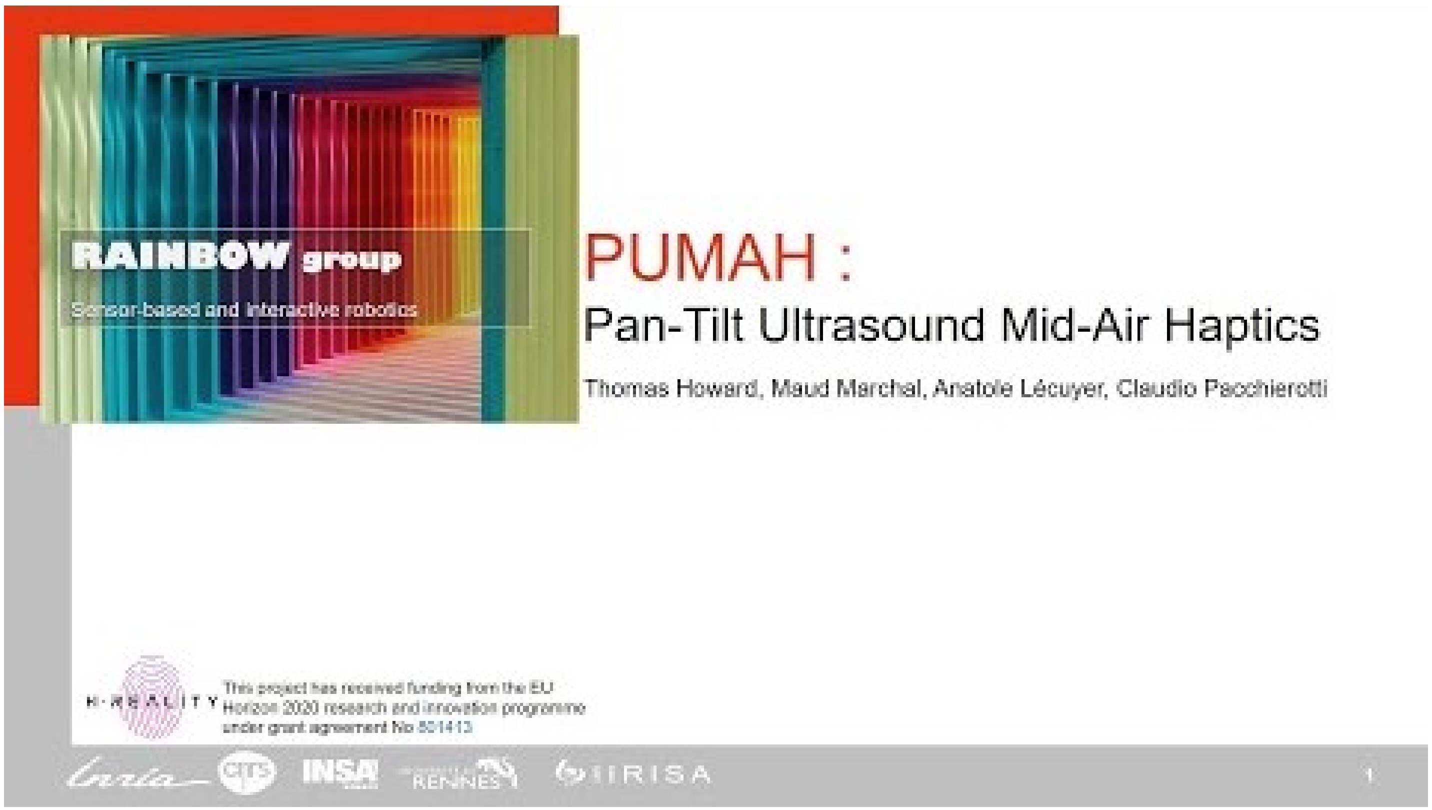


Perspectives: non-contact/mid-air haptics

- Ultrasound haptic devices

Perspectives: non-contact/mid-air haptics

- Ultrasound haptic devices



Thank you!

Questions?