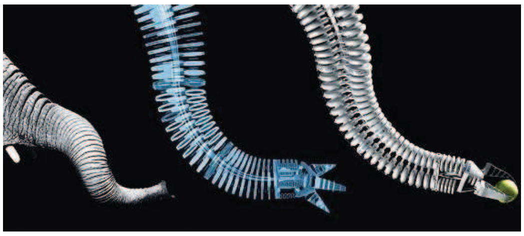
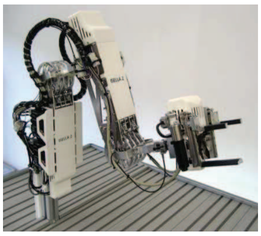
Muscoskeletal robots and wearable devices on the basis of cable-driven actuators

Musculoskeletal robots and wearable devices on the basis of cable-driven actuators

Martin Haegele, Christophe Maufroy, Werner Kraus
Fraunhofer IPA
Head of Department „Robotics and Assistive Systems“
Tel.: +49 711 970 1203, {mmh, cmm, wek}@ipa.fhg.de

Outline

- Motivation for alternative designs for robot manipulation
- Alternative transmission designs: from DoHelix via ISELLA to Myorobotics
- The Myorobotics Tool-Kit and product visions
- Wearable cable driven robots
- Current R&D at Fraunhofer IPA
- Conclusion

Robots today: main configurations and properties

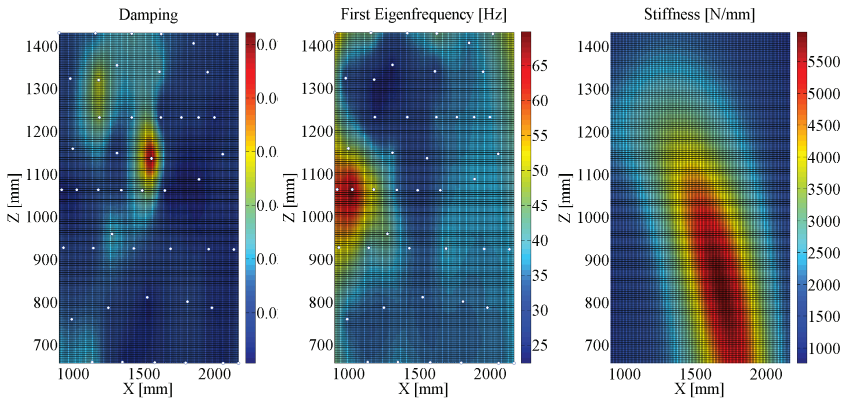
Criterion	Industrial robots					Arm modules	Advanced small robots	
Kinematics	SCARA	Gantry		Articulate robot arm		Joint modules	Light-weight arm	Safe robot
Pay load [kg]	<10	<50	<500	<10	<200	~5 for typical 6DOF config.	7	4
Degrees of freedom, DOF	4-5	3-6		5-6	6	Scalable, typic. 2-7 DOF	7	6
Repeatability [mm]	0,01	0,1	0,3	0,02	0,05	0,1 in typic. 6DOF config.	0,05	0,05
Sensor guidance	✓	✓		✓			✓	
Reach; workspace radius [m]	<1	variable		2,5	>3	1,5 in typic. 6 DOF config.	1,2	0,8
Unit cost[T€]	25	50	100	30	60	5/DOF	100	50
Example	Adept Cobra 800	Reis RL		ABB IRB140		Schunk ERB 0 Powerball	KUKA LBR4+	KUKA KR5Si

Source: EFFIROB Study 2011 (IPA)
Data and cost are taken from available material (2011) and may not correspond to depicted product examples.

Robot dynamics and accuracy

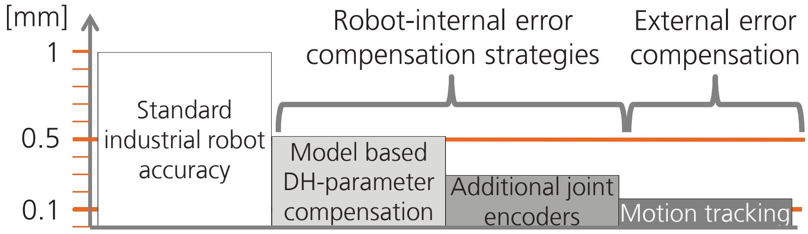
Robot **dynamics** in Cartesian space:

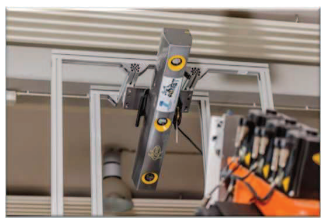
- damping (KR60)
- first eigen-frequency
- stiffness (KR125)



Measured in typical plane of robot's workspace measured from its first axis (source ISG Stuttgart).

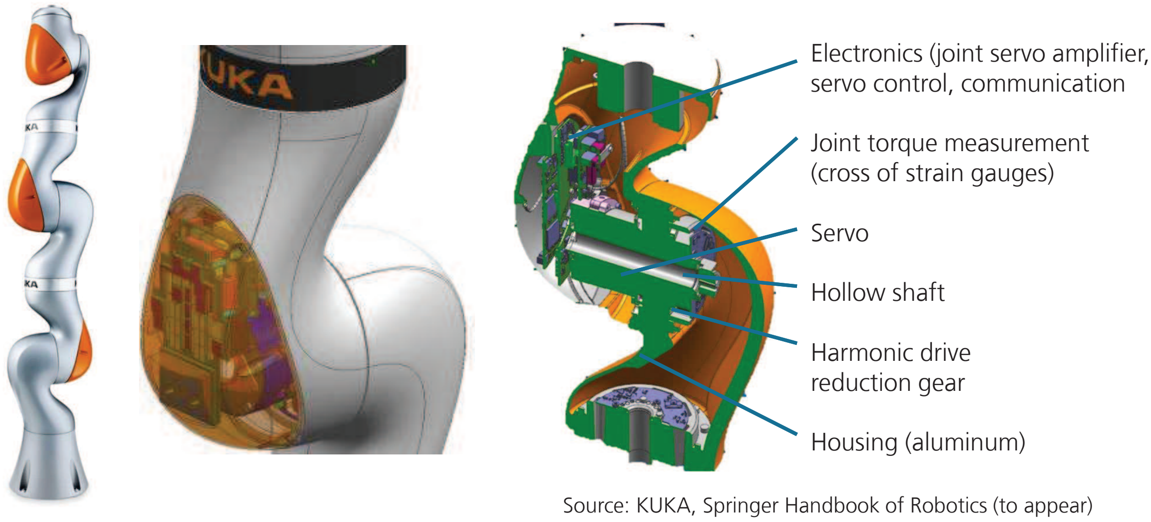
Motion **accuracy**





Major cost item: transmission module

Example: 7-axis KUKA iiwa, programmable compliance arm



Source: KUKA, Springer Handbook of Robotics (to appear)

Fraunhofer IPA

Motivation for alternative designs for manipulators

Pull:

- Modularity for customizable kinematic designs
- Softness/compliance and intrinsic safety
- Cost

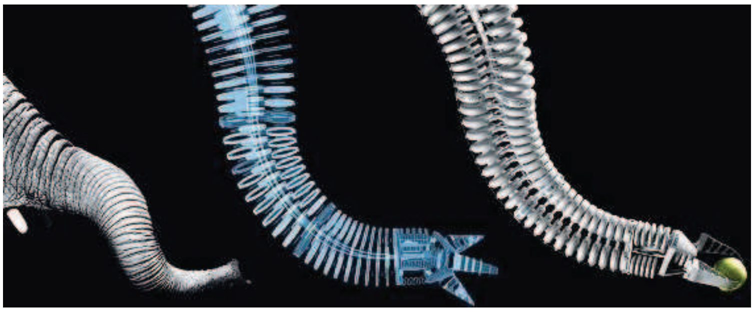
Push:

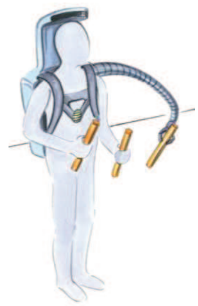
- New materials, manufacturing processes
- Application niches with need for new solutions.

→ Need for alternative kinematic and transmission designs for manipulators

Fraunhofer IPA

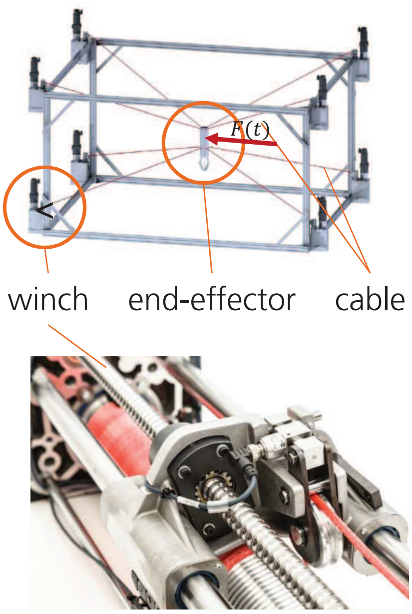
Example bionic handling assistant: Integration of structure, actuation, and manufacturing





Source: Fraunhofer, Festo, mdr

Example cable driven parallel robots: Modularity, dynamics and low-cost

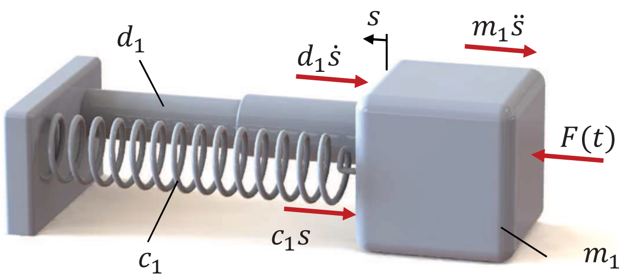


Hybrid position-force control:

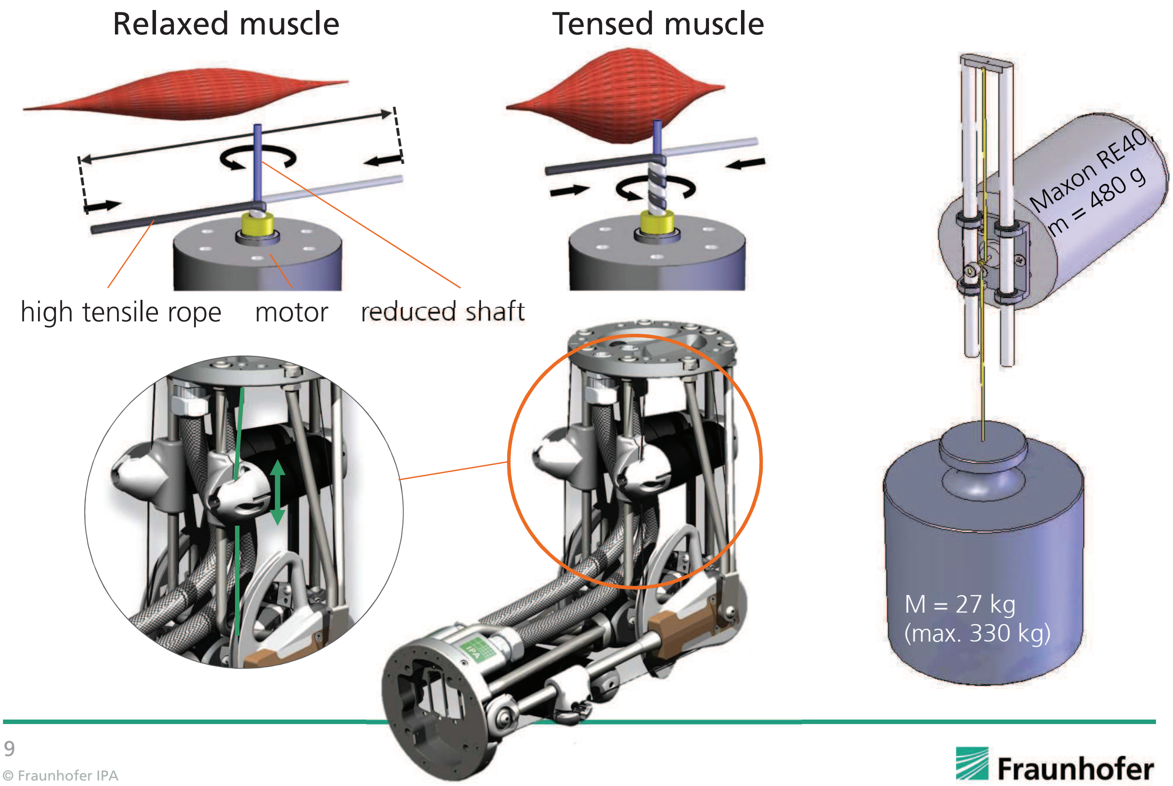
- Simulation of spring-mass-damper system
- Admittance control law

$$\ddot{s} = \frac{1}{m_1}(F(t) - d_1\dot{s} - c_1 s)$$

- Force $F(t)$ measured by cable force sensors



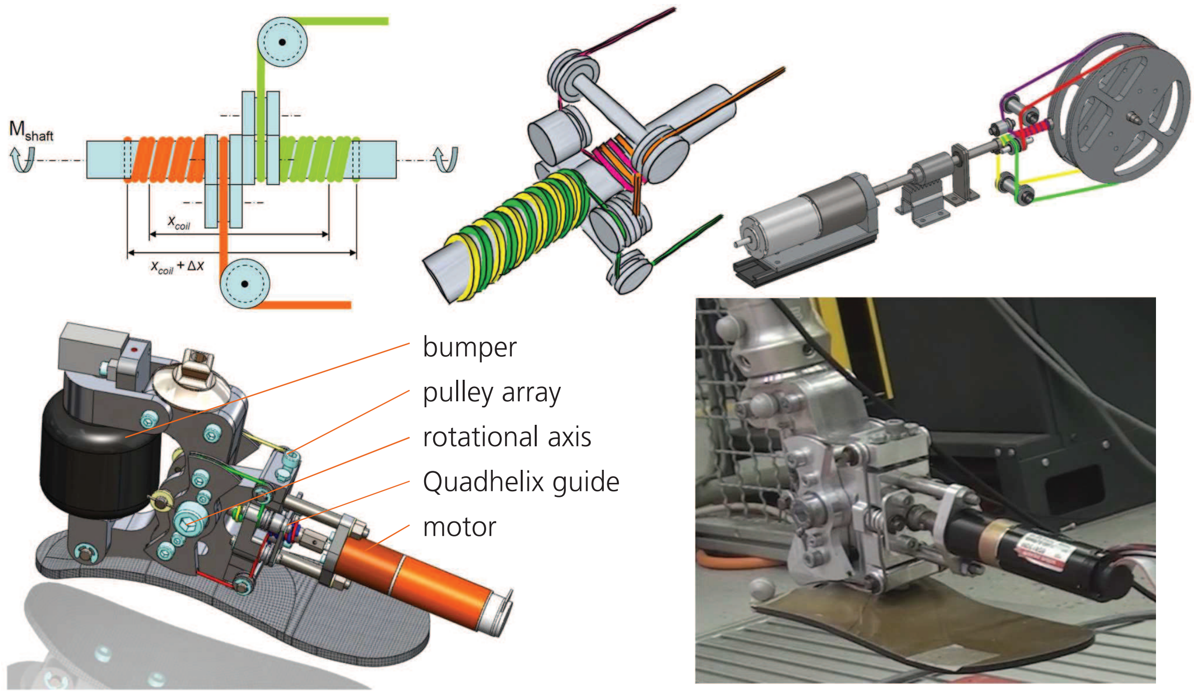
Cable driven serial joints: The Do-Helix principle



9
© Fraunhofer IPA

Fraunhofer IPA

From Do-Helix via Quadhelix to Isella



10
© Fraunhofer IPA

Fraunhofer IPA

ISELLA: full scale robot arm

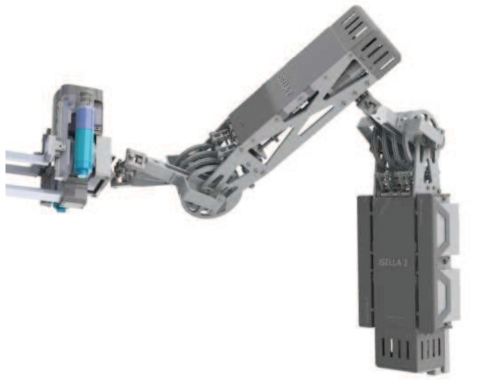
Improvements

- Use of QuadHelix-Drives
- Dead load to payload 1:1
- Load-designed components

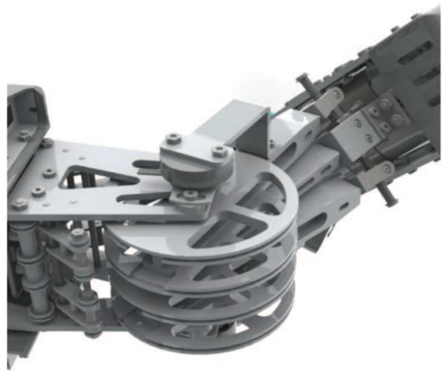
Advantages

- Only 1 drive per degree of freedom
- 4 DoF arm with 4 motors
- 3 DoF gripper with 3 motors

2 DoF Module



2 modules with gripper – front view



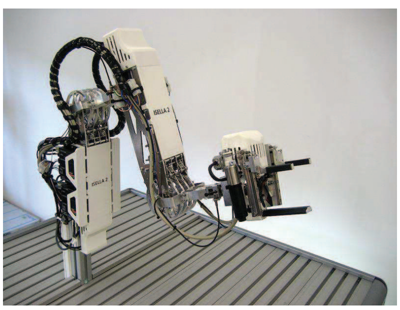
2 DoF rotation axis - detailed view

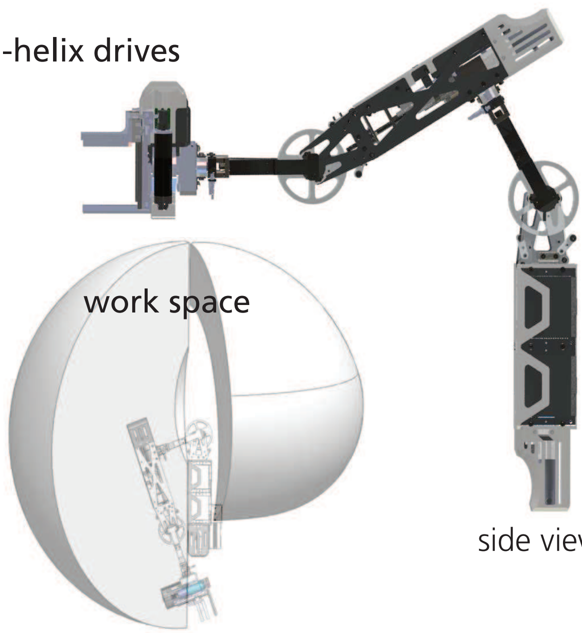
Fraunhofer IPA

ISELLA: full scale robot arm

Next generation of ISELLA with quad-helix drives

1 drive per degree of freedom
4 Drives → 4 DoF
Weight arm: ~ 8,5 kg
Weight gripper: ~ 2,5 kg
Payload: ~9 kg
Realized: Full arm including gripper





side view

Fraunhofer IPA

Challenges

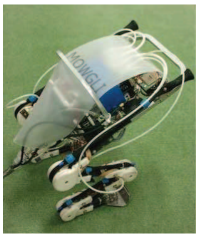
- Complex hardware and software
- Custom-made, hardly available

BioBiped

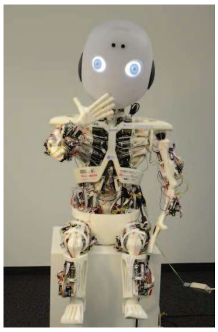
Kenjiro

ECCERobot

Mowgli



Roboy



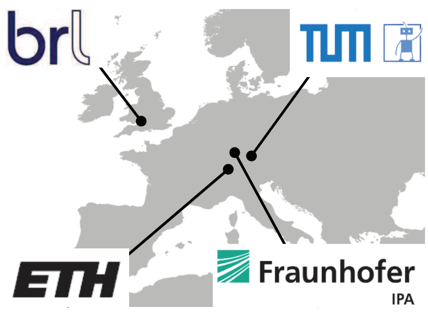
The Myorobotics project

- Complex hardware and software
  - modular hardware
  - modular communication infrastucture
  - user-friendly software suite
- Custom-made, hardly available
  - rapid prototyping
  - cost-efficient production
  - open-source

MYOROBOTICS

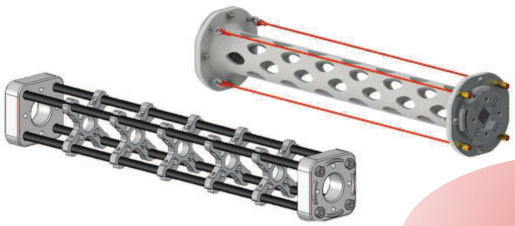
Framework for musculoskeletal robot development

EU FP7 Project – 4 Partners,
http://www.myorobotics.eu/

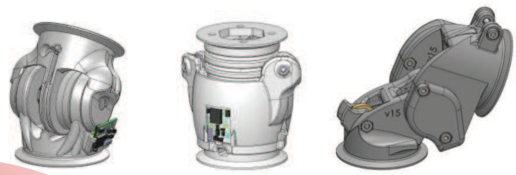


Design Primitive Library (DPL)

MYO-Bones

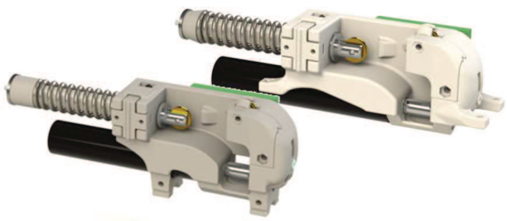


MYO-Joints

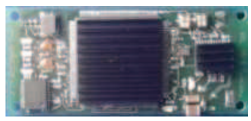


MYO-Robot

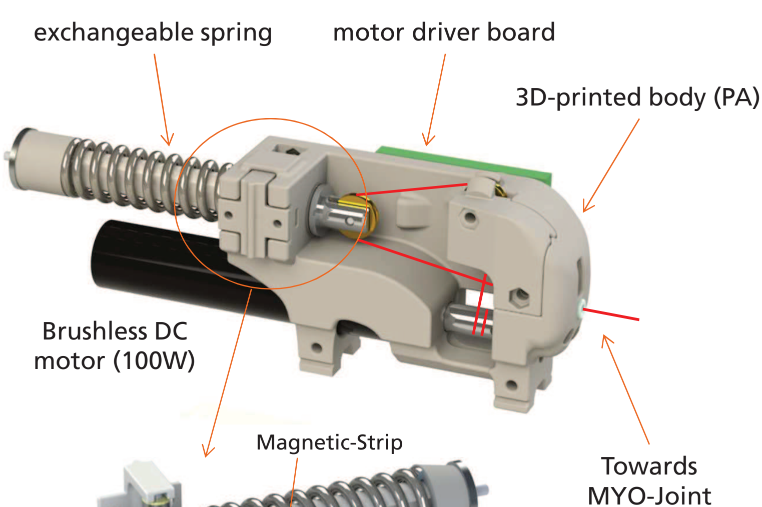
MYO-Muscles

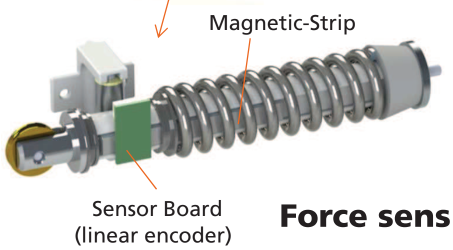


MYO-Ganglion

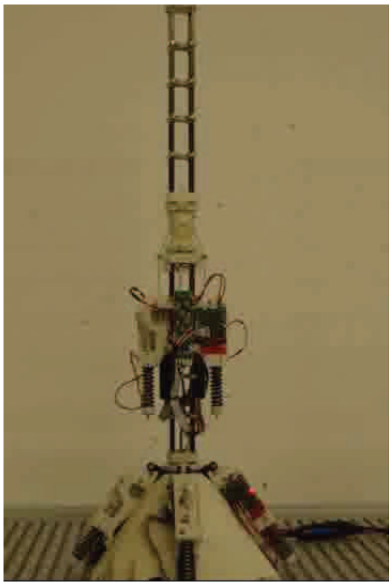


DPL – MYO-Muscle



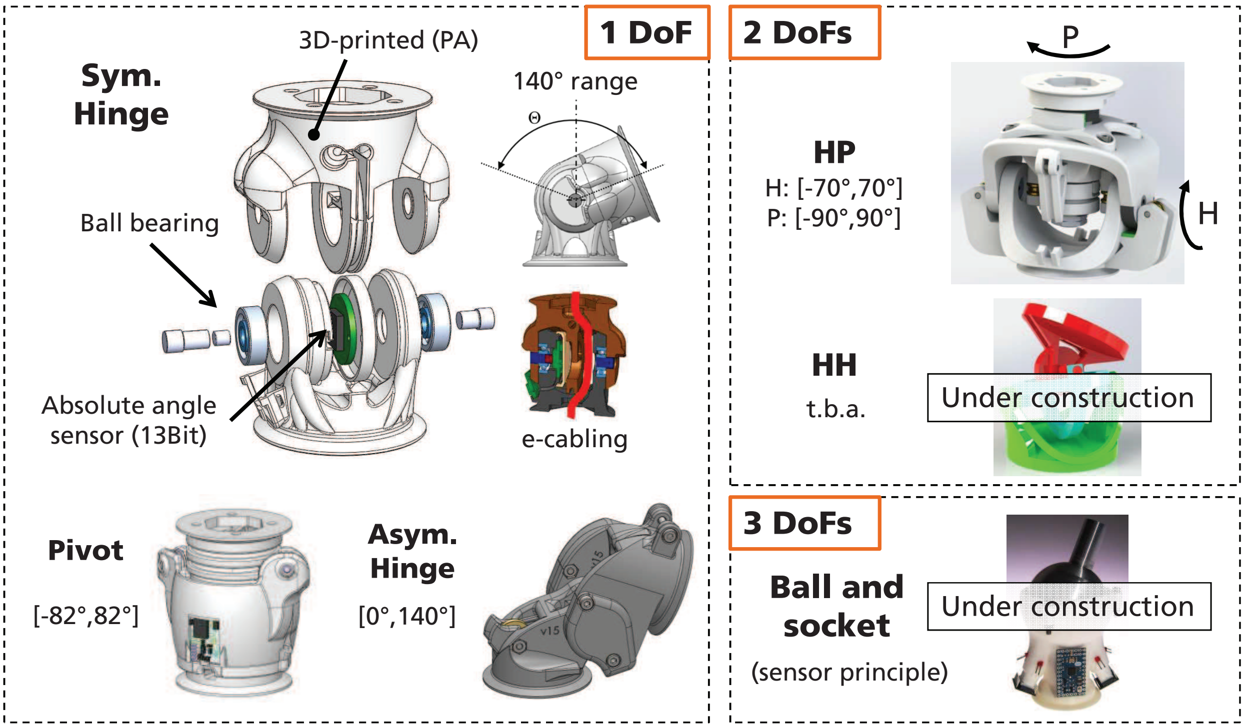


Force sensing



Compliance with fixed motor positions

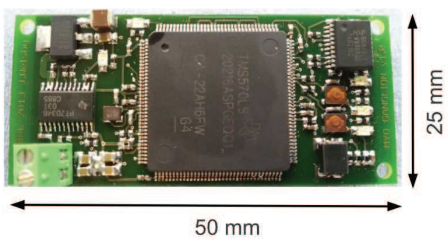
DPL – MYO-Joints



Fraunhofer IPA

DPL – MYO-Ganglion

brl



- Local processing and communication unit
  - 32-bit floating point controller
  - 140MHz clock
  - FlexRay, CAN, SPI

- Communications:

SPI	2 Mbit/s	motor drivers
CAN	1 Mbits/s	sensors
FlexRay	10 Mbits/s	MYO-Ganglion, Computer

- Control modes: (work in progress)

muscle: position, drive current, force
joint: torque, position, velocity

+ local control loops (such as reflexes)

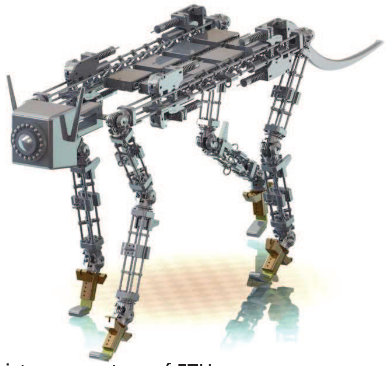
Picture courtesy of BRL

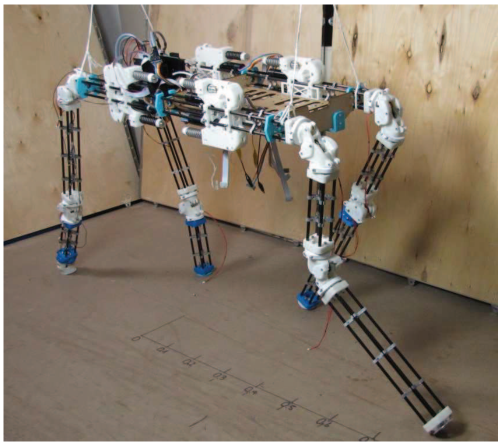
Fraunhofer IPA

DPL – Integration and demonstrators

First small series of hardware

(status mid-March 2014)





Both pictures courtesy of ETH

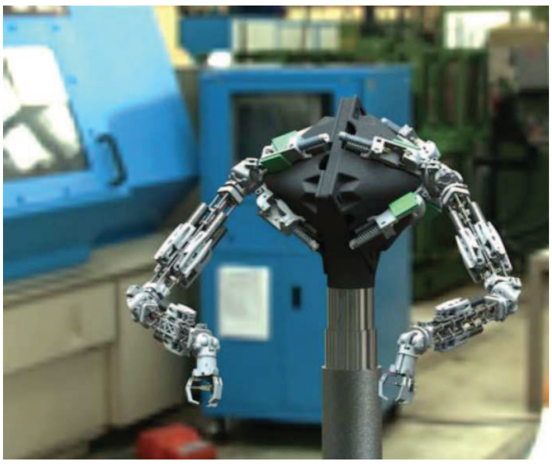
Fraunhofer IPA

Product visions

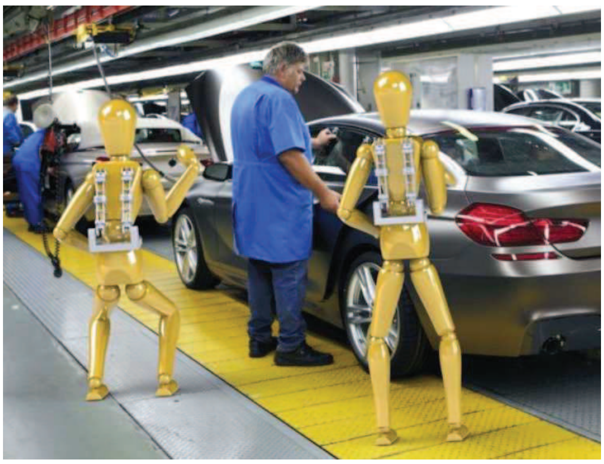
Compliance (safety, energy efficiency)

Versatility (customization/reconfiguration)

Cost-effectiveness (initial & recommission)



Robot assistant



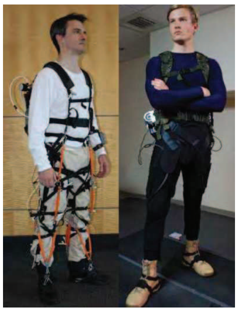
Wearable devices

Fraunhofer IPA

Examples of Wearable Robots (based on cables)

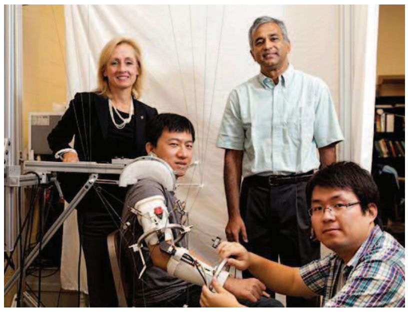
Muscle Suit
(Koba Lab)

Soft Exosuit
(Harvard Biodesign Laboratory)

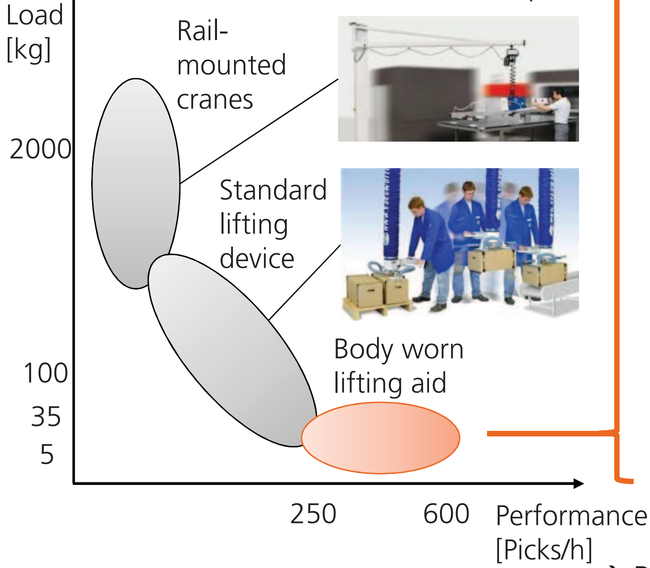


Ergoskeleton
(Strong Arm Vest)

Cable-Driven Exoskeleton
(University of Delaware)



Requirements and structure of body worn lifting aid



→ BMBF Joint Project: body worn lifting aid

Transition to expand lifting aid

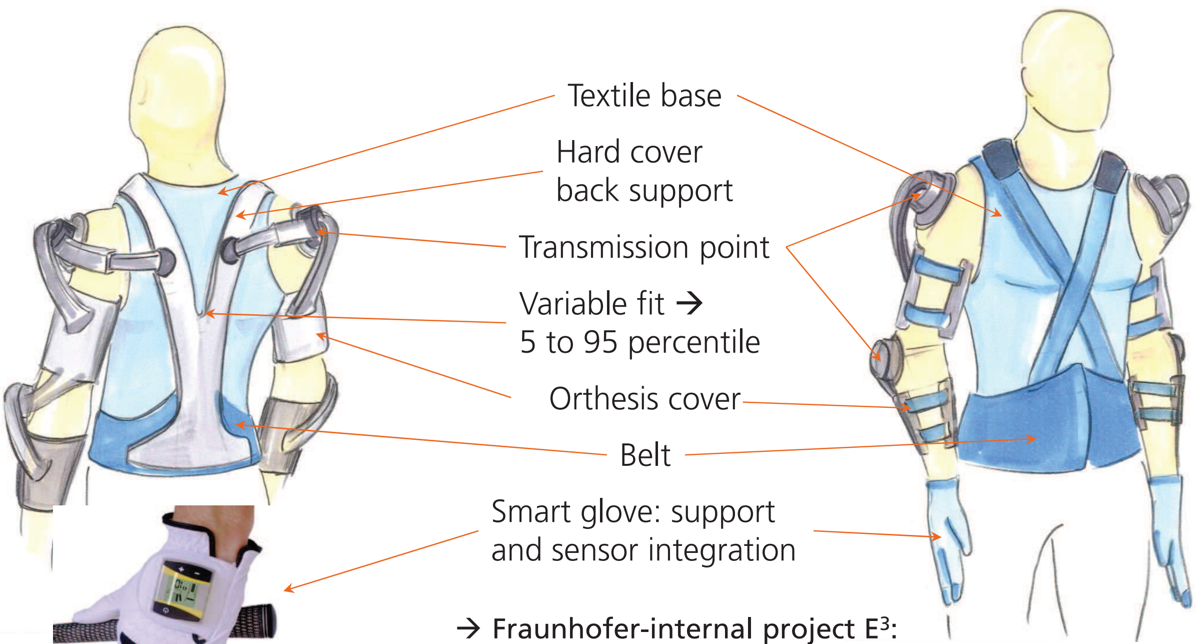
Requirements

- Support for overhead work
- Body-fitting structure with minimal interfering geometry
- Flexible force assistance where cable can only provide forces in one direction

Transition →

Fraunhofer IPA

Current development at IPA: Body worn lifting aid

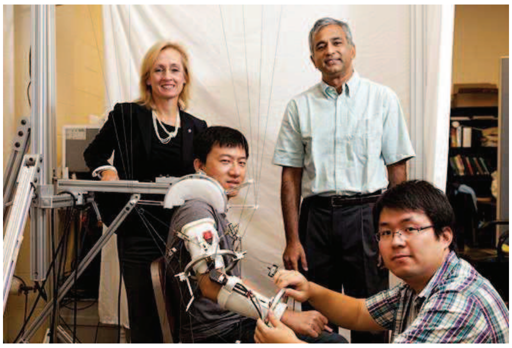


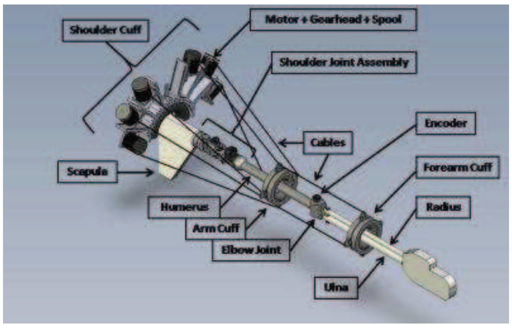
→ Fraunhofer-internal project E³: Assistive Systems for Manufacturjng

Fraunhofer IPA

Cable-driven exoskeleton

- Advantages of cable-driven actuators:
  - Light-weight force transmission
  - Adaptable (modular, scalable etc.)
  - Motor can be placed close to the human body
- Disadvantages:
  - Unilateral force transmission
  - Cable wear, especially dynamic load due bending at pulley
- Trends:
  - Cable-actuators, textiles as alternatives to stiff, robot-resembling exoskeletons





Fraunhofer IPA

Fraunhofer

IPA

FIRST INTERNATIONAL SYMPOSIUM ON »SOFT ROBOTICS« IN GERMANY

Fraunhofer IPA Symposium **F 291**
23-24 June 2014
Stuttgart