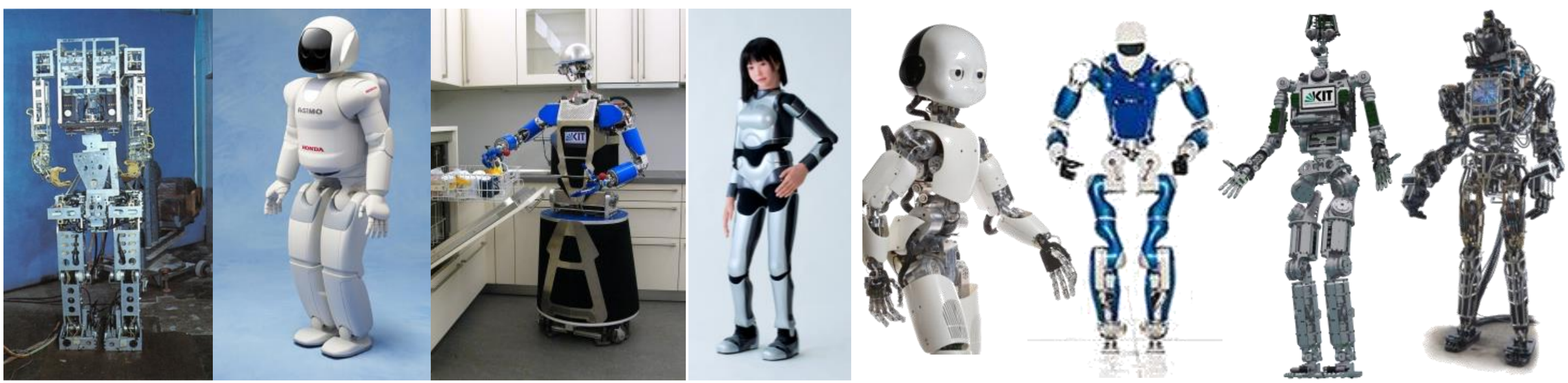
Karlsruhe Institute of Technology

Robotics II: Humanoid Robotics

Chapter 2 – Building Humanoids

Tamim Asfour

KIT-Department of Informatics - Institute for Anthropomatics and Robotics - High Performance Humanoid Technologies (H^2T)



Exam, ECTS, …

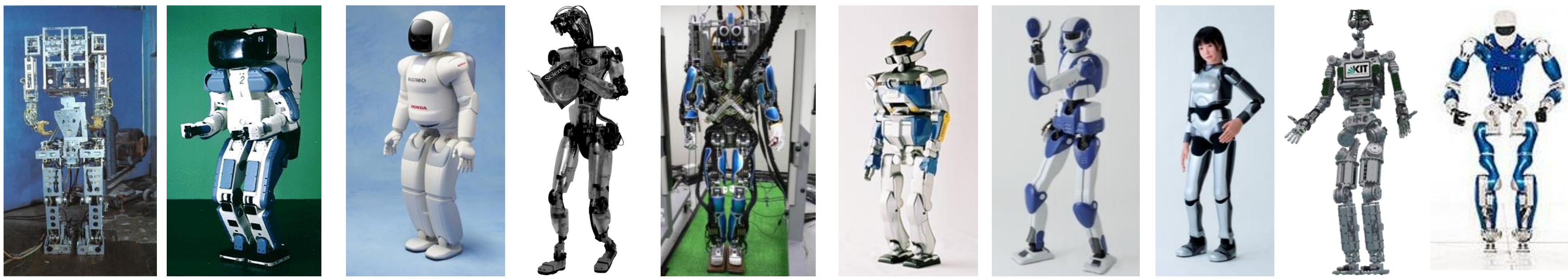
- Written exam
- Date: 11. September 2017 11:00 – 12:00
- Registration for the exam via **ilias**
- 3 ECTS

Chapter 2

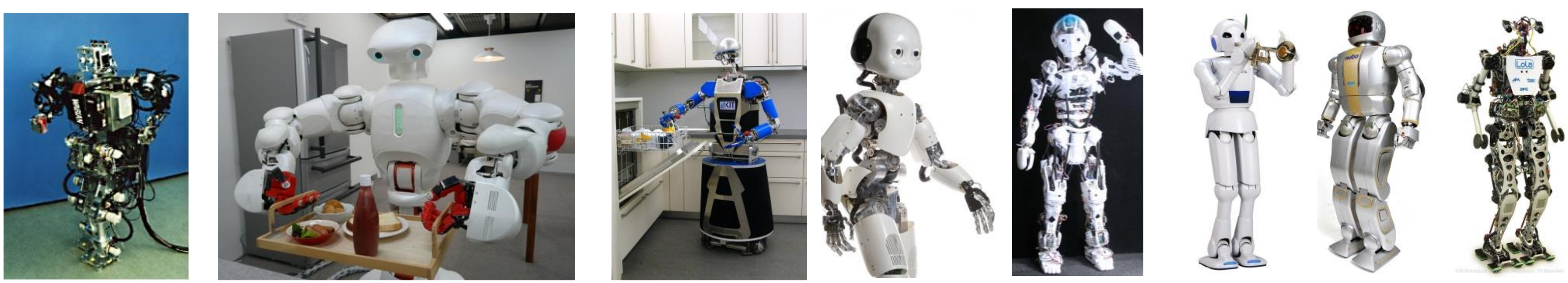
- Building and engineering humanoid robots
  - History of humanoid robotics
  - DRC Robotic Challenge
  - Biomechanical models of the human body
  - Mechatronics of humanoid robots

HUMANOID ROBOTS AND HUMANOID PROJECTS

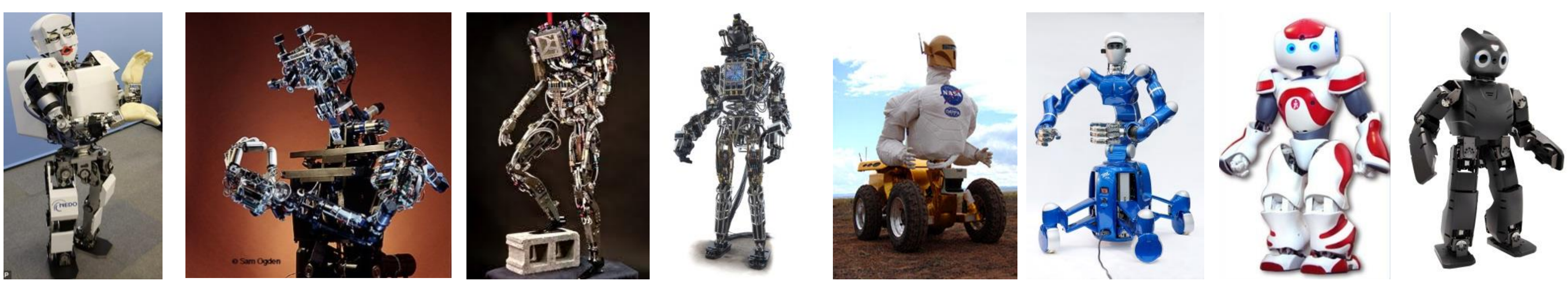
Humanoid robotics has made progress !



WABOT-1 P2 ASIMO DB CB HRP-2 HRP-4 HRP-4C ARMAR-IV Toro



WABIAN Twendy-one ARMAR-III iCub kojiro Partner Robot HUBO Lola



KOBIAN Cog Petman Atlas Robonaut Justin NAO DARwIN-OP

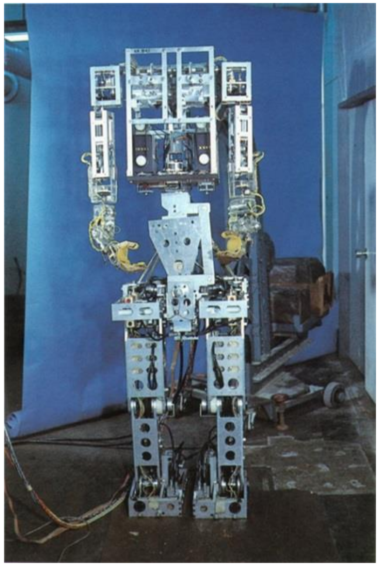
Famous humanoid robots

… without a specific order

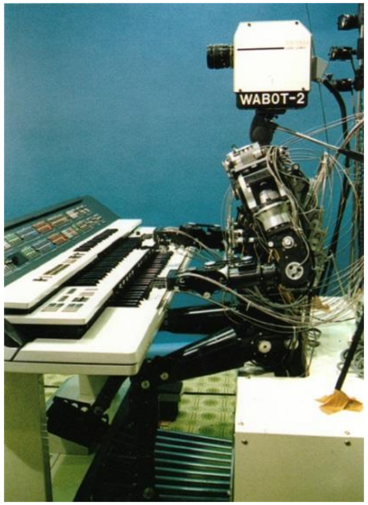
- WABOT-1 (Waseda University, Japan)
- Wabian (Waseda University, Japan)
- ASIMO (Honda, Japan)
- HRP-2 (Kawada Insdustry, Japan)
- HRP-4C (Kawada Insdustry, Japan)
- Toyota Partner Robot (Toyota, Japan)
- HUBO (Korean Institute of Science and Technology, KIST, Korean)
- Petman (Boston Dynamics, USA)
- Atlas (Boston Dynamics, USA)
- Cog (MIT, USA)
- iCub (Italian Institute of Technology, Italy)
- Robonaut (NASA, USA)
- NAO (Aldebaran, France)
- REEM (PAL Robotics, Spain, United Arab Emirates)
- Justin (DLR, Germany)
- ARMAR (KIT, Germany)
- …

WABOT

- WABOT-1:
  - First Full-scale anhtropomorphic robot of the world
  - Developed 1970-1973 at Tokyo's Waseda University under Prof. Ichiro Kato
  - WABOT is an acronym for WAseda roBOT
  - Capabilities
    - communication with person in Japanese
    - bipedal walking



- WABOT-2:
  - development 1980-1984
  - "specialist robot" able to play the keyboard
  - able to read musical score with its eye and play tunes on an electronic organ



Wabian

- Developed by Waseda University, Japan
- Current model: Wabian-2R (since 2006)

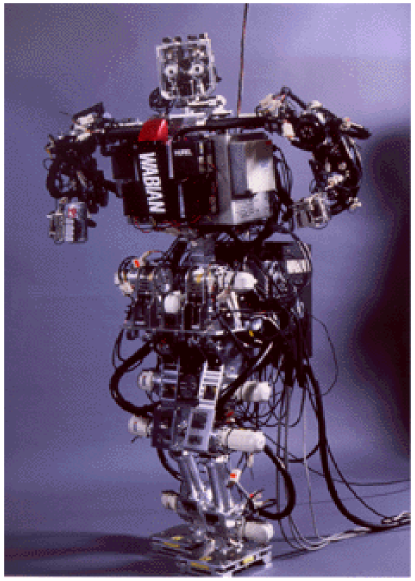
- Usage:
  - human motion simulation
  - Goal: robot should be the human's partner
  - Walking experiments with a walk-assist machine

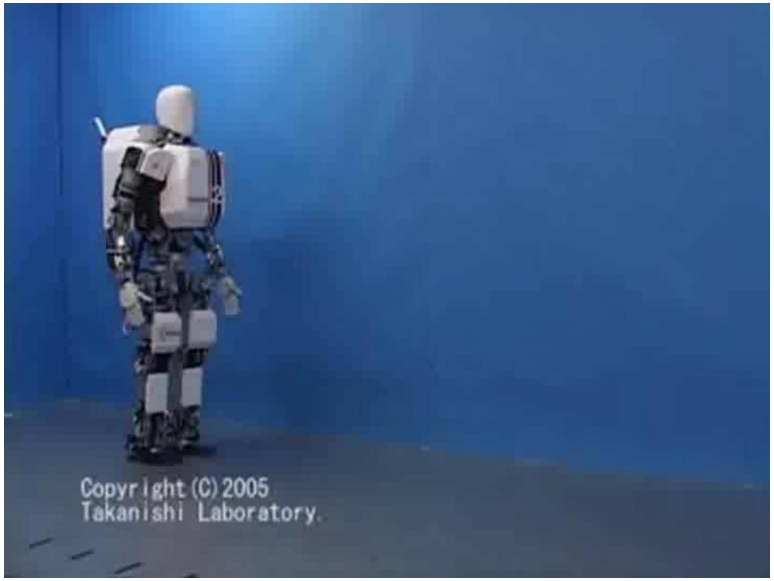
- Sensors:
  - 6-axis force/torque sensors
  - Photo sensors
  - Magnetic encoders
  - Gyro sensor



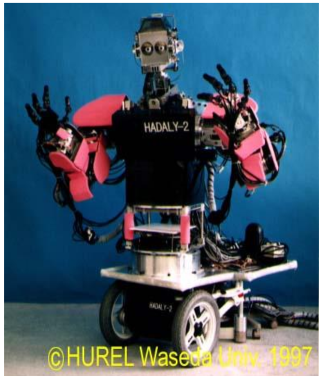
WABIAN

Waseda University, Tokyo, Japan





Hadaly-2



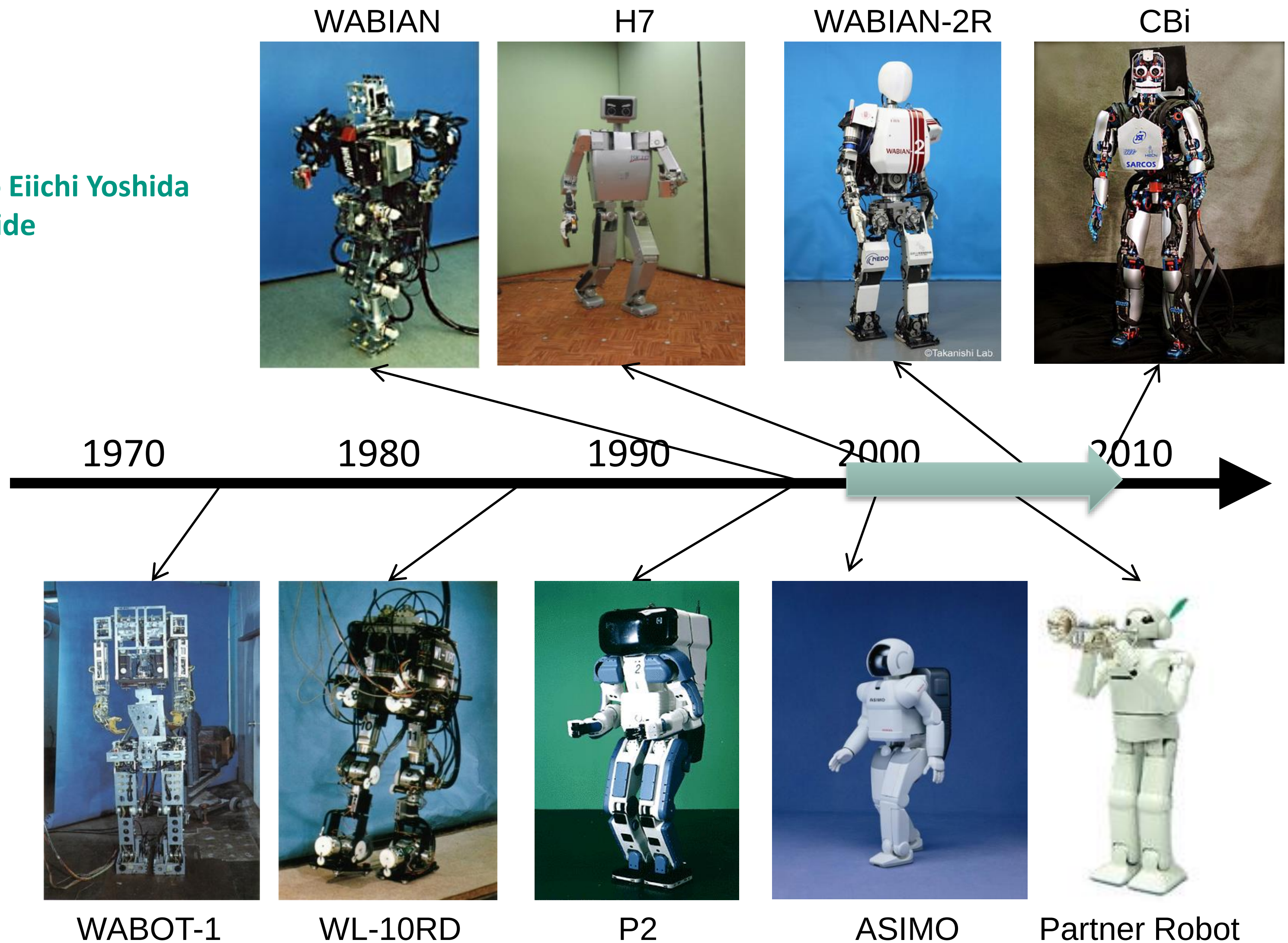
WABIAN

WABIAN-2

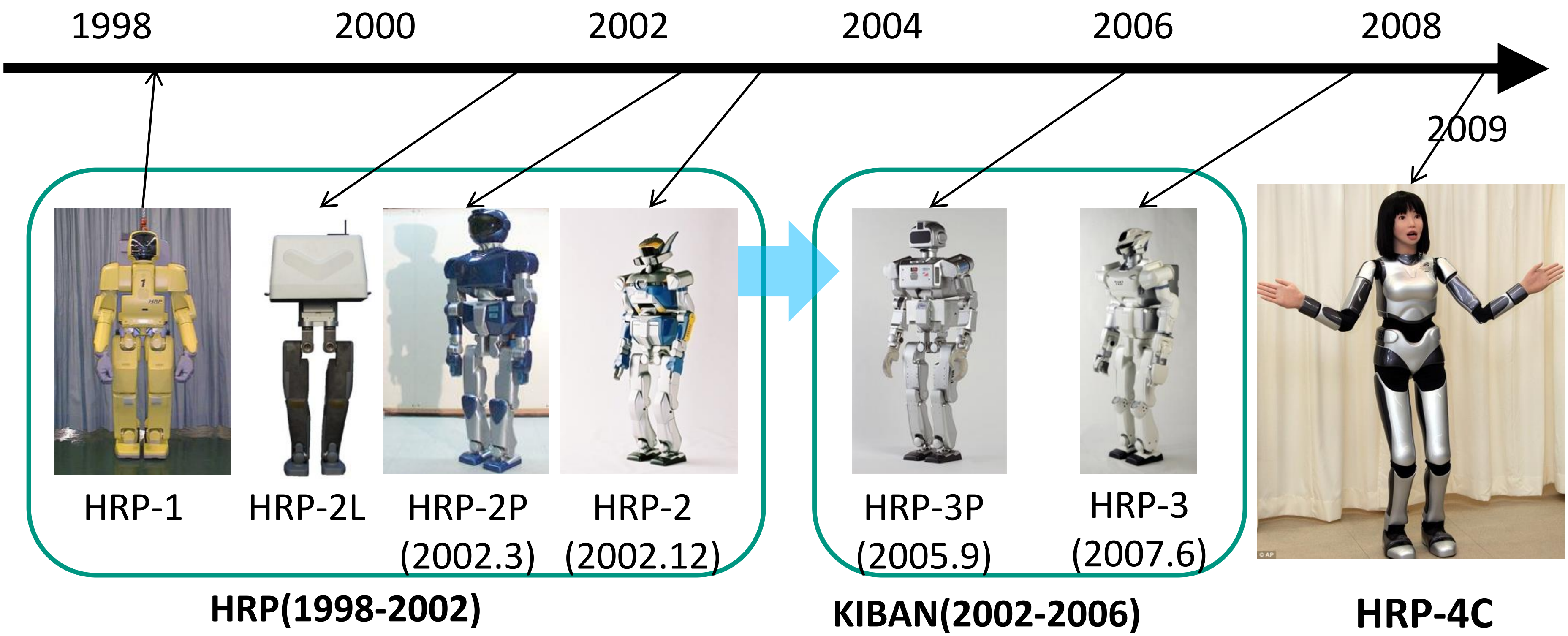
Ogura et al. (2006), Human-like Walking with Knee Stretched, Heel-contact and Toe-off Motion by a Humanoid Robot, IROS 2006

History in Japan

Thanks to Eiichi Yoshida
for this slide



HRP series: from HRP-1 to HRP-4C



AIST: http://www.is.aist.go.jp/humanoid

Thanks to Eiichi Yoshida for this slide

HRP-2

HRP = **H**umanoid **R**obotics **P**roject

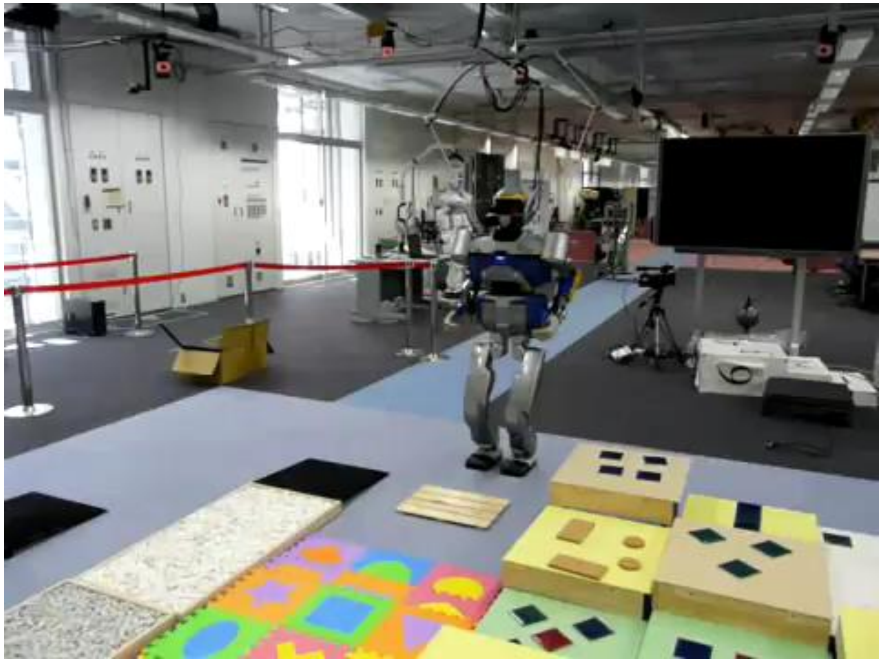
- Developed by Kawada Industries (Japan), together with the Humanoid Research Group of National Institute of Advanced Industrial Science and Technology (AIST) in 2002
- In use in research labs worldwide
- Research areas include:
  - Walking (on uneven surfaces)
  - footstep planning
  - Tipping-over control
  - Grasping and manipulation
  - Human-interactive operations
- Height: 154 cm
- Weight: 58 kg
- 30 DOF







HRP-2



Walking on uneven terrain

Walking through the wall

Standing up and panel assembly

HRP-2

Dancing

Humanoids 2005

Specifications of HRP-2

Dimensions	Height	1,540 [mm]
	Width	600 [mm]
	Depth	340 [mm]
Weight inc. batteries		58 [kg]
D.O.F.		Total 30 D.O.F.
	Head	2 D.O.F.
	Arm	2 Arms x 6 D.O.F.
	Hand	2 Hands x 1 D.O.F.
	Waist	2 D.O.F.
	Leg	2 Legs x 6 D.O.F.
Walking Speed		up to 2.0 [km/h]

Specifications of HRP-3

Dimensions	Height	1,606 [mm]
	Width	693 [mm]
	Depth	410 [mm]
Weight inc. batteries		68[kg]
D.O.F.		Total 42 D.O.F.
	Head	2 D.O.F.
	Arm	2 Arms x 7 D.O.F.
	Hand	2 Hands x 6 D.O.F.
	Waist	2 D.O.F.
	Leg	2 Legs x 6 D.O.F.

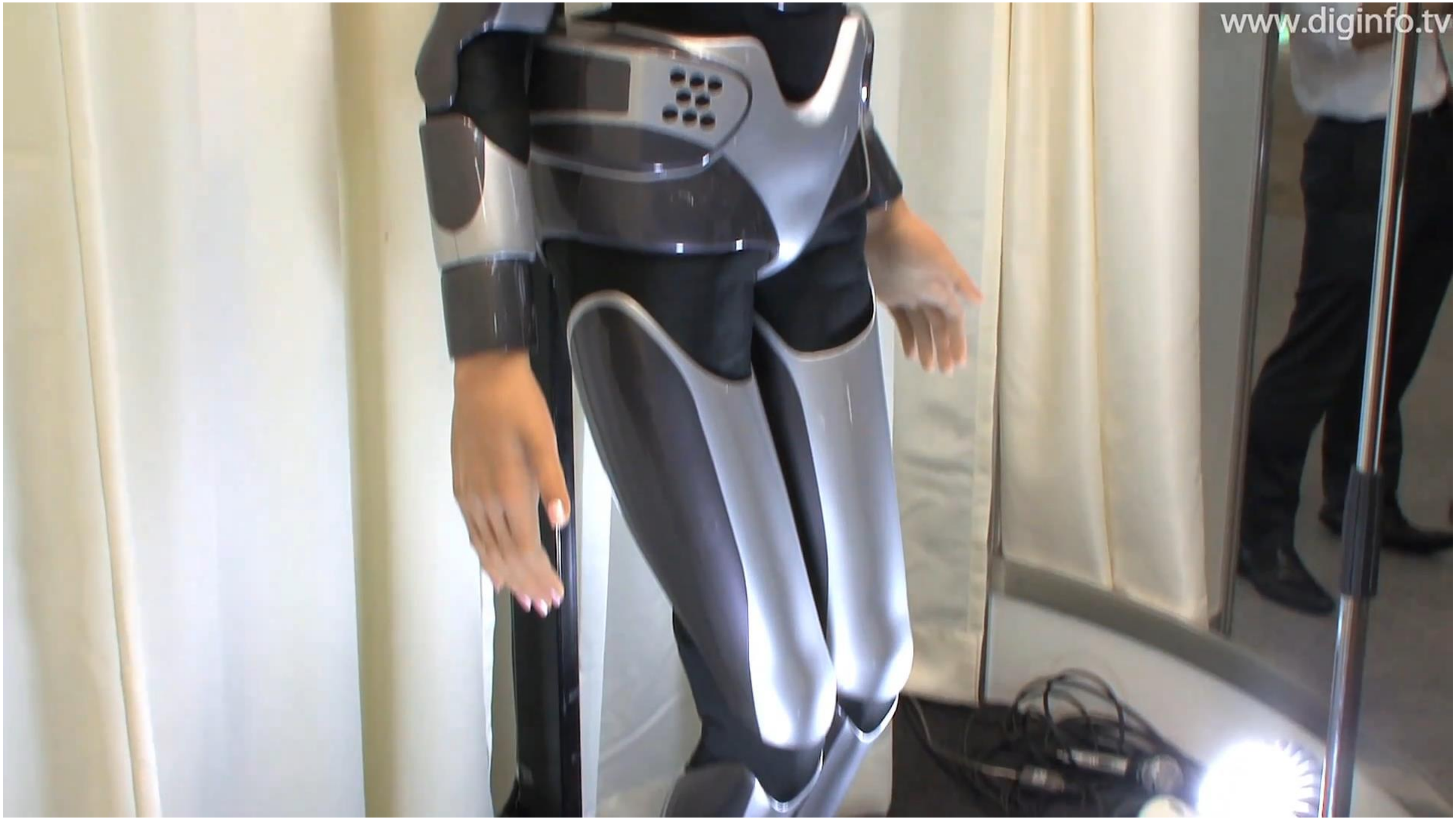
HRP-4C

- Developed by Kawada Industries (2009)
- Shape and joints based on the 1997/1998 Japanese body dimension database
  - average figure of a young Japanese female, realistic head
- Capabilities:
  - human-like motion
  - speech and ambient sound recognition
  - Singing, Dancing
  - Mimicking human facial and head movements
- Possible applications:
  - Entertainment industry
  - Human simulator for evaluation of devices
- Height: 170 cm
- Weight: 43 kg
- 42 DOF

Specifications of HRP-4C

Height		1,580 [mm]
Weight inc. batteries		43 [kg]
D.O.F.		Total 42 D.O.F.
	Face	8 D.O.F.
	Neck	3 D.O.F.
	Arm	2 Arms × 6 D.O.F.
	Hand	2 Hands × 2 D.O.F.
	Waist	3 D.O.F.
	Leg	2 Legs × 6 D.O.F.
CPUs	Motion Controller	Pentium® M 1.6 [GHz]
	Speech Recognition	VIA C7® 1.0 [GHz]
Sensors	Joints	Incremental Encoder
	Sole	6-axes Force Sensor
	Body	Posture Sensor
	Head	Receiver of Bluetooth® Microphone
Batteries		NiMH DC 48V

HRP-4C



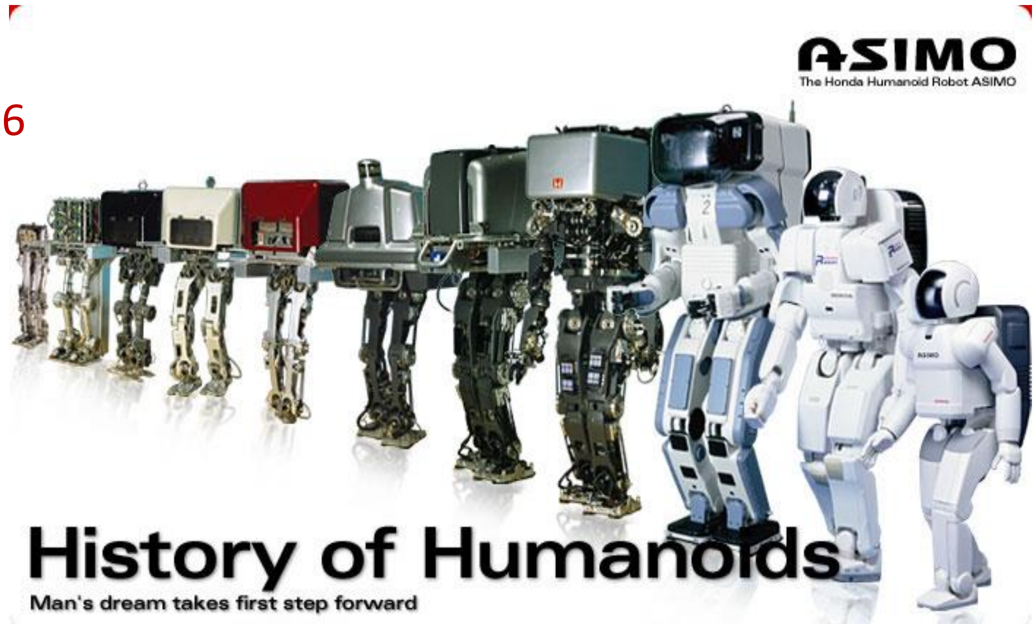
ASIMO

- Developed by Honda
- Asimo is acronym for: "*Advanced Step in Innovative Mobility*" -
  - also: asi (japanese: tomorrow), mo (mobility)
  - japanese pronounciation: "ashimo" (means: “also legs”)
- Capabilities:
  - Bipedal locomotion
  - motion resembles human walking motion
- First introduced in 2000
  - Now in the 4th generation
- latest generation (2014):
  - weight: 50 kg
  - height: 130 cm
  - 57 DoF

ASIMO

Honda Robots, Japan

1986



2000

http://world.honda.com/ASIMO/history/history.html

ASIMO, Nov. 2011

http://asimo.honda.com

Toyota Partner Robot

Karlsruhe Institute of Technology

- Series of humanoid robots starting 2000

- Latest version (2012):
  - Human Support Robot (HSR)
  - Able to pick up objects from tables and from the floor
  - Controllable via tablet PC
  - height: 2.7 to 4.3 feet
  - weight: 70 lbs
  - Speed: 1.8 mph
  - Main sensors: Prosense (MS Kinect) and stereo cameras

From left to right: the walking type playing the trumpet, the wire type, i-Foot, TPR-ROBINA

Sony: SDR-3X, QRIO

Sony Dream Robot (SDR-3X)

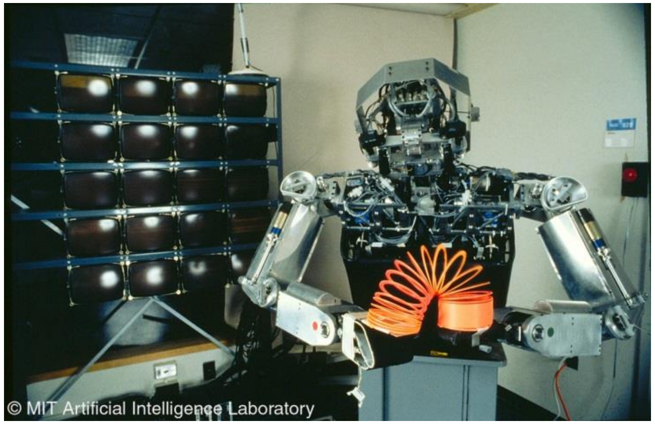
QRIO

On January 26, 2006, on the same day as it announced its discontinuation of AIBO and other products, Sony announced that it would stop development of QRIO.

Cog

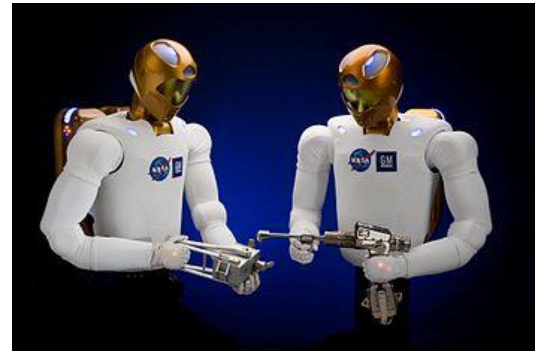
- Research project at MIT 1994-2003 under Rodney Brooks
- Torso with head and arms
- Goal: Cognitive information processing
- Capabilities:
  - Recognition of people and objects
  - Learns how to move by handling objects.

- 22 DoF:
  - two 6-DOF arms
  - 3-DOF torso
  - 4-DOF neck
  - 3-DOF in the eyes

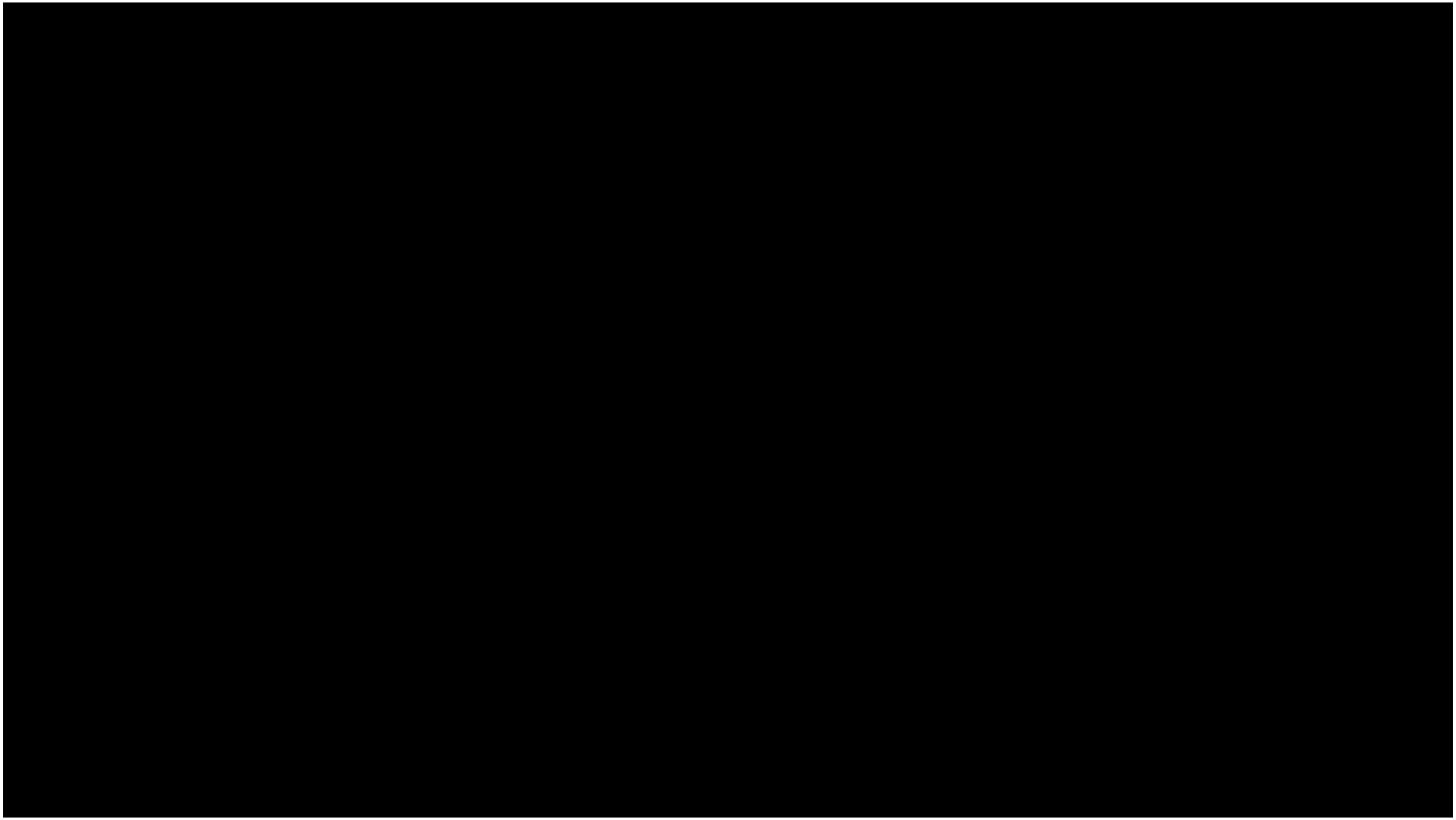


Robonaut

- Humanoid robot project by NASA, first introduced in 2002
- Objectives:
  - Achieve high dexterity, ability to use tools
  - Robot should work together with astronauts
  - Tele-operation
- Two generations: R1 and R2
- Several lower bodies
- One robot is active on the International Space Station
- 42 DOF
- more than 350 sensors

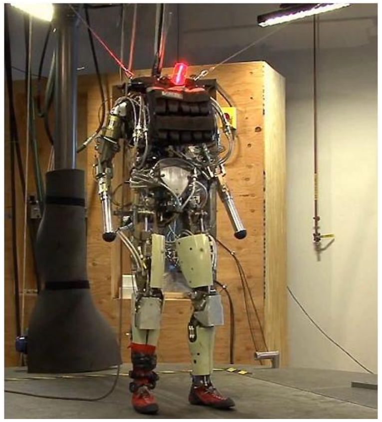


NASA Robonaut 2



Petman (DARPA, Boston Dynamic)

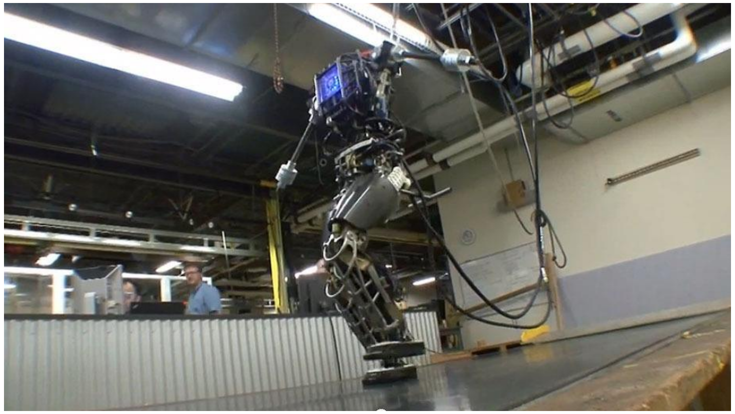
- Acronym for: Protection Ensemble Test Mannequin
- Developed by Boston Dynamics for the US army, funded by DARPA
- Introduced 2010
  - Humanoid robot for testing chemical protection suits for soldiers
  - Simulation how a soldier stresses protective clothing under realistic conditions.
- Capabilities:
  - Walking and balancing, bending and doing a variety of suit-stressing calisthenics during exposure to chemical warfare agents
  - Simulation of human physiology within the protective suit by controlling temperature, humidity and sweating
- Height: 175 cm
- Weight: 80 kg



Petman (DARPA)

Atlas (DARPA)

- Developed by Boston Dynamics for the US army, funded by DARPA, introduced 2013
- Based on Petman
- Capabilities:
  - Bipedal walking, leaving the upper limbs free to lift, carry, and manipulate the environment
  - In challenging terrain, Atlas can climb using hands and feet.
- Some goals to achieve at DARPA Robotics Challenge 2014:
  - getting in and out of a vehicle
  - driving it
  - opening a door
  - using a power tool
- Intended use: search and rescue tasks
- Height: 180 cm
- Weight: 150 kg
- 28 DoF

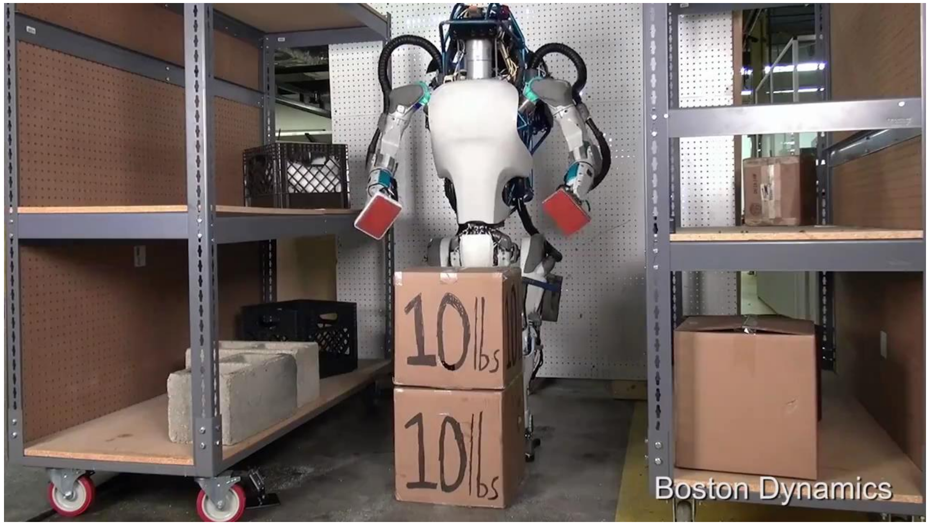


Atlas (DARPA) at MIT, 2013

Boston Dynamics, August 15, 2015

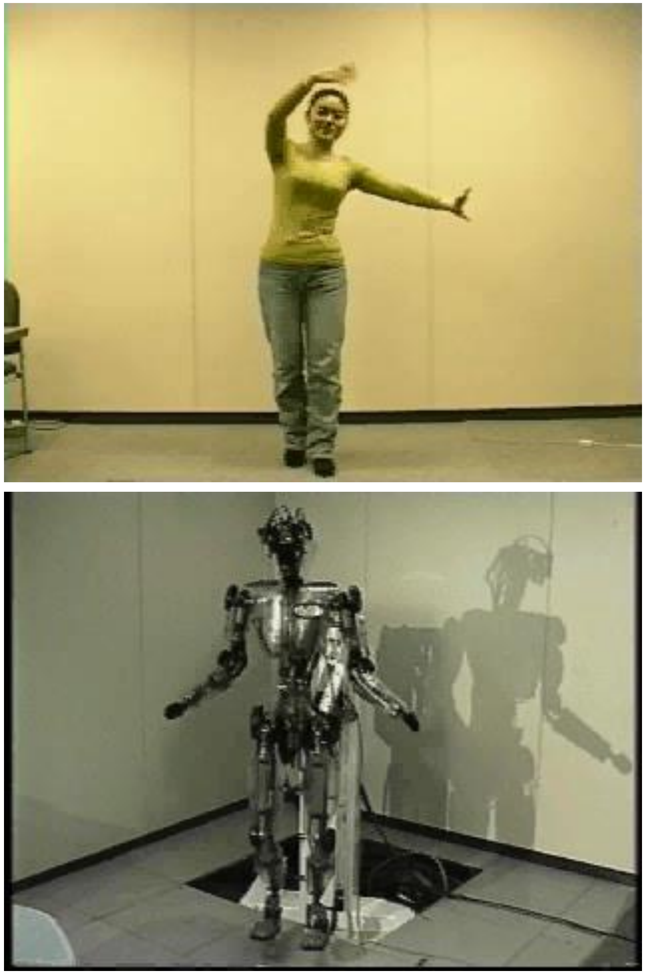
Talk by Marc Raibert

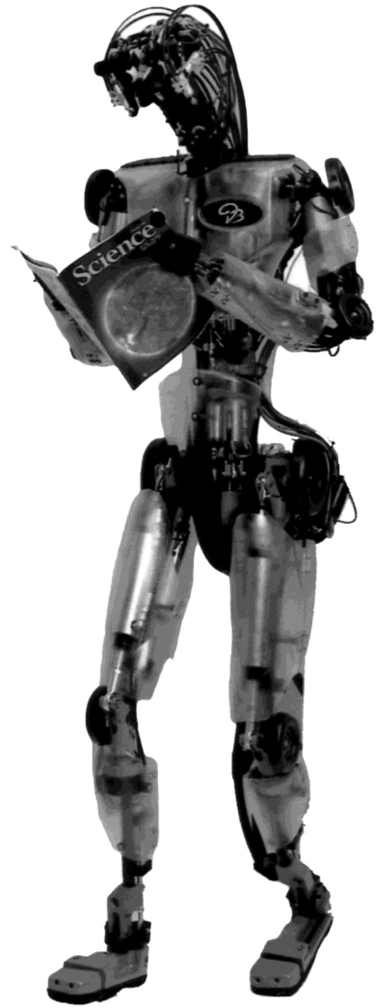
Boston Dynamics Atlas, February 2016

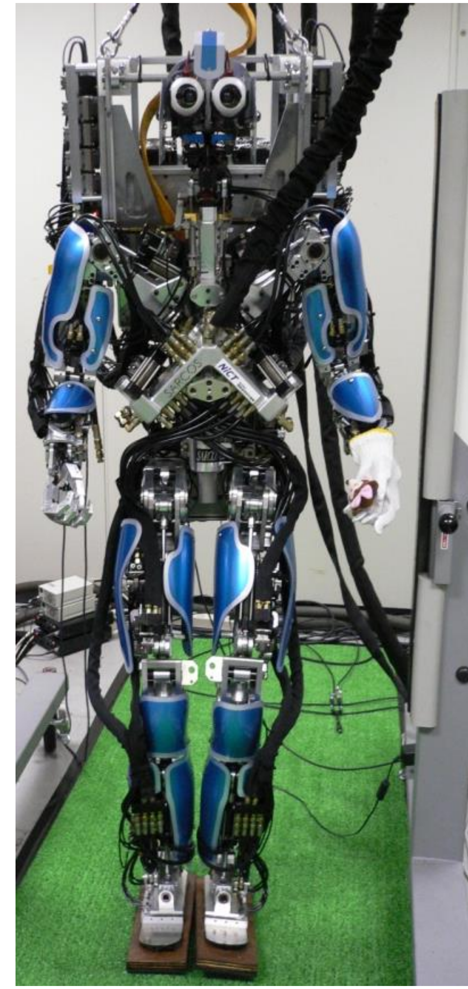


Boston Dynamics Handle (Feb. 2017)

Sarcos robots at ATR

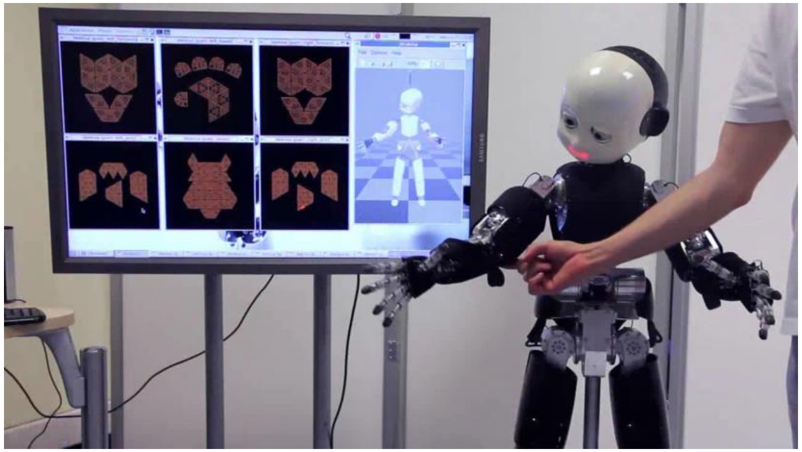

DB (Dynamic Brain)

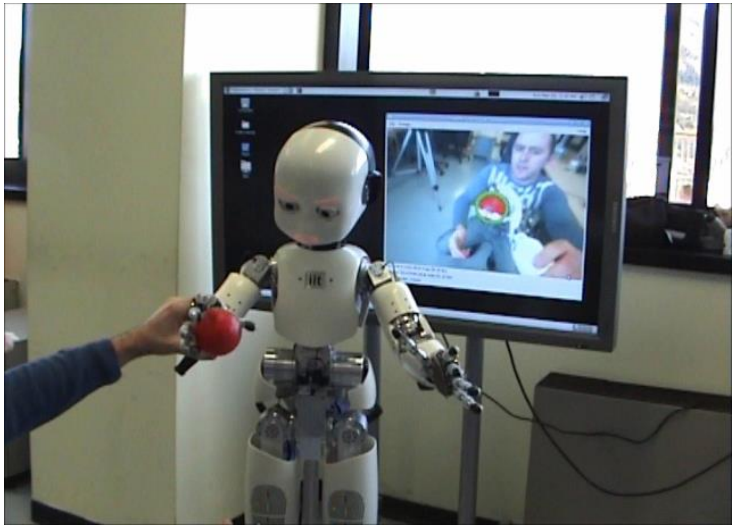



CB (Computational Brain)

iCub

- Acronym: cub for "Cognitive Universal Body"
- Development 2004 - today
- Designed by RobotCub Consortium of several European universities
- Built by Italian Institute of Technology (IIT)
- Dimensions similar to a 3 year old child
- Usage:
  - Research into human cognition and artificial intelligence
  - Embodied cognition hypothesis: Human-like manipulation plays a vital role in the development of human cognition.
  - The robot was designed to test this hypothesis by allowing cognitive learning scenarios to be acted out by an accurate reproduction of the perceptual system and articulation of a small child so that it could interact with the world in the same way that such a child does.
- height: 100 cm, weight: 22 kg , 53 DoF

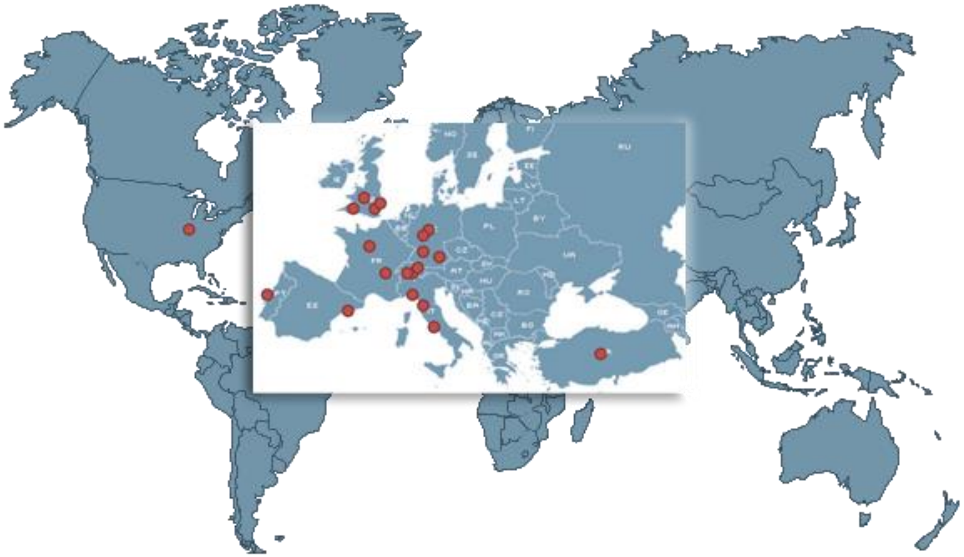




iCub

iCub is an **open source** international endeavour initially funded by the EU project **RobotCub**

- a full humanoid robot
- is 104cm, weighs 22 kg
- has 53 degrees of freedom
- can crawl, sit and manipulate
- open design as LGPL/GPL



Nao

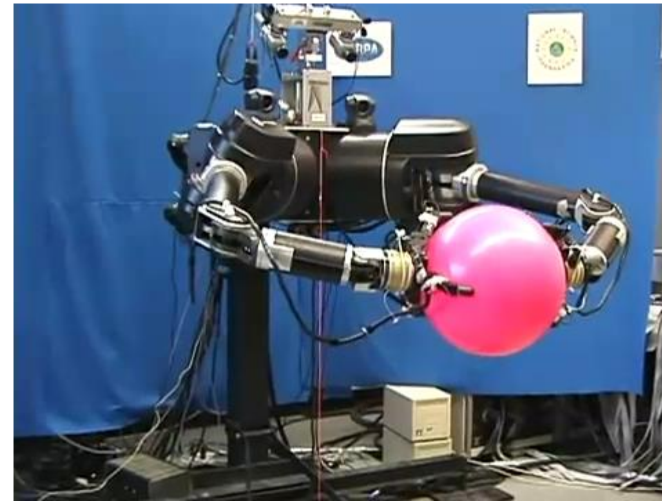
- Developed by Aldebaran Robotics, France
- Introduced 2008, Nao Next Gen 2011
- Capabilities:
  - Bipedal walking
  - Getting up from the floor
  - Facial and shape recognition
- Usage:
  - Research and education
  - RoboCup robot soccer competitions
- Sensors:
  - ultrasound
  - stereo cameras (HD)
- Height: 58 cm
- Weight: 4.3 kg
- 21 to 25 DoF

NAO, 2012

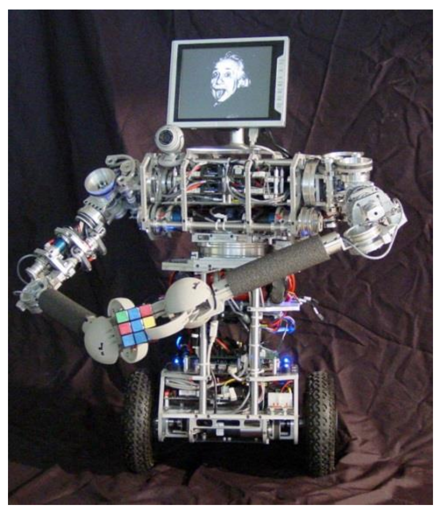
Dexter and uBot, University of Massachusetts

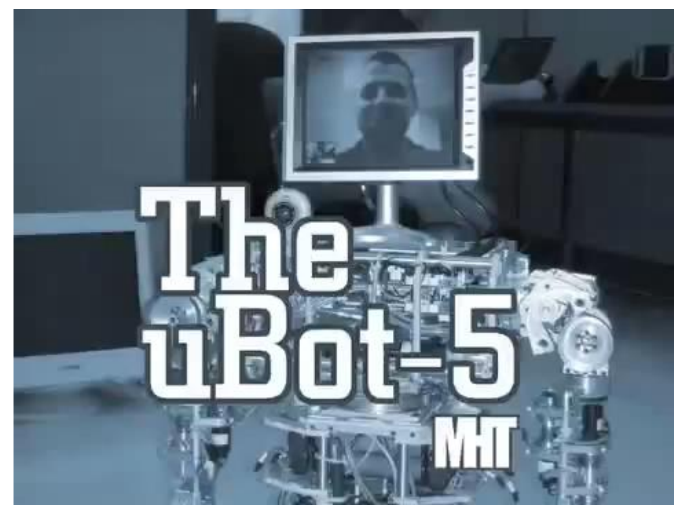
- Dexter: designed to study bi-manual dexterity designed to help us study the acquisition of concepts and cognitive representations from interaction with the world.

- uBot: research platform for mobile manipulation



Throw and balancing





KHR and HUBO

- Developed by the Korea Advanced Institute of Science and Technology (KAIST) and released on January 6, 2005
- Hubo has voice recognition and synthesis faculties, as well as sophisticated vision in which its two eyes move independently of one another.

	KHR-0 (2001)	KHR-1 (2002)	KHR-2 (2004)	HUBO (KHR-3) (2005)	Albert HUBO (2005)	HUBO 2 (KHR-4) (2008)	HUBO 2 Plus (2011)
Weight	29 kg	48 kg	56 kg	56 kg	57 kg	45 kg[3]	43 kg
Height	110 cm	120 cm	120 cm	125 cm	137 cm	125 cm	130 cm
Walking speed	-	1.0 km/h	1.2 km/h	1.25 km/h	1.25 km/h	1.5 km/h	1.5 km/h
Continuous operating time	-	-	-	60 minutes	60 minutes	120 minutes	120 minutes
Degrees of Freedom	12	21	41	41	66	40	38

DASL Drexel Autonomous Systems Lab METlab

http://en.wikipedia.org/wiki/HUBO

Justin and Toro, DLR

- Advanced mechantronics and compliance control
- Balancing

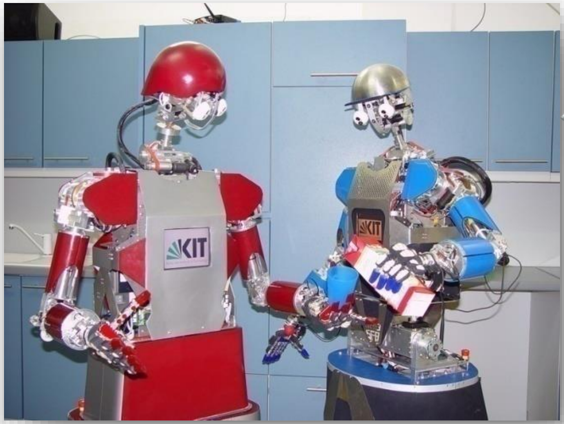
KIT Karlsruhe Institute of Technology

The ARMAR family

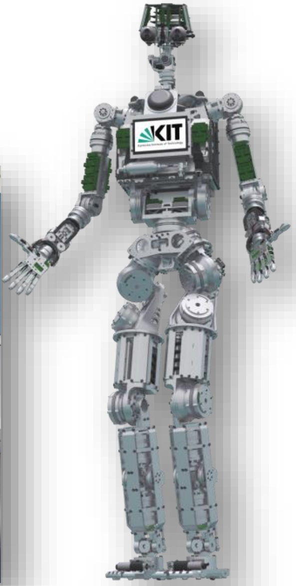
ARMAR, 2000

ARMAR-II, 2002

ARMAR-IIIa, 2006



ARMAR-IIIb, 2008

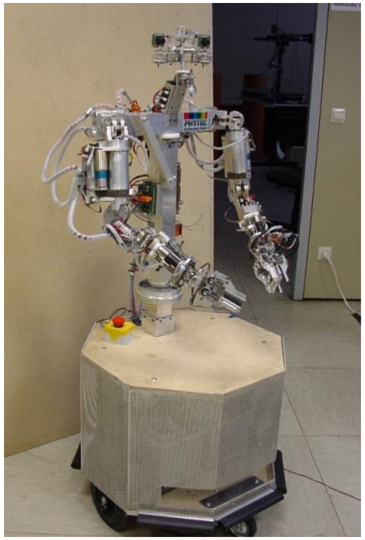
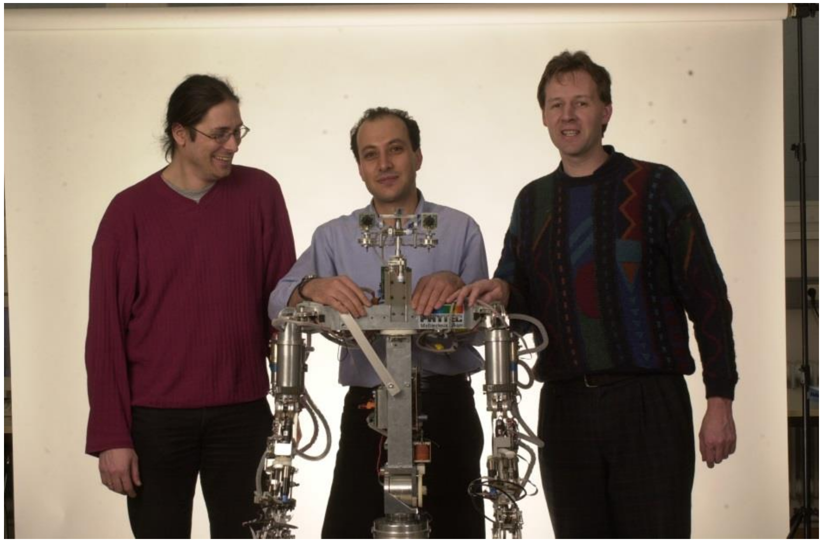


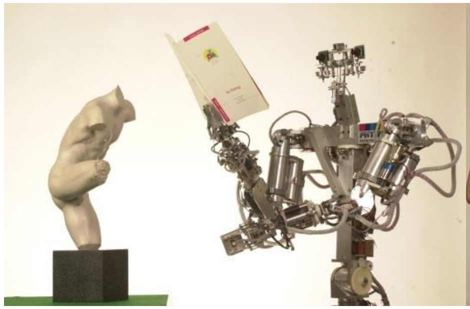
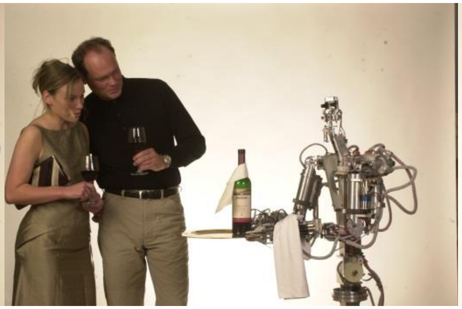
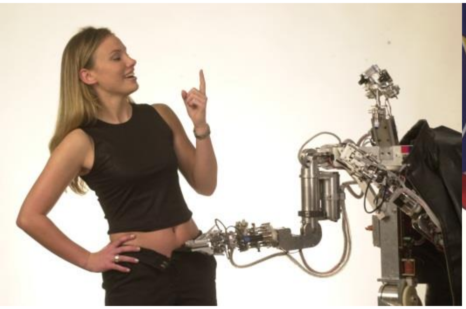
ARMAR-IV, 2011

H2T

ARMAR-I

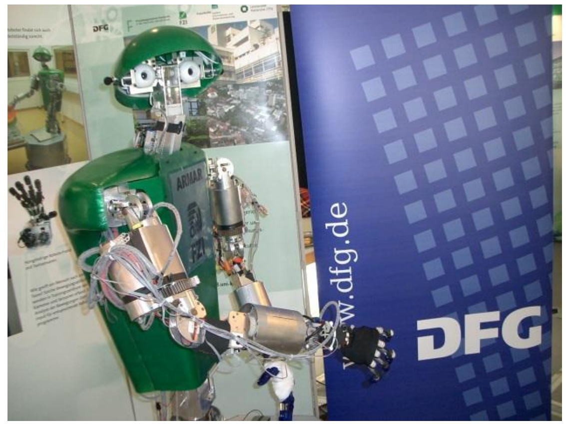
- 1999-2004

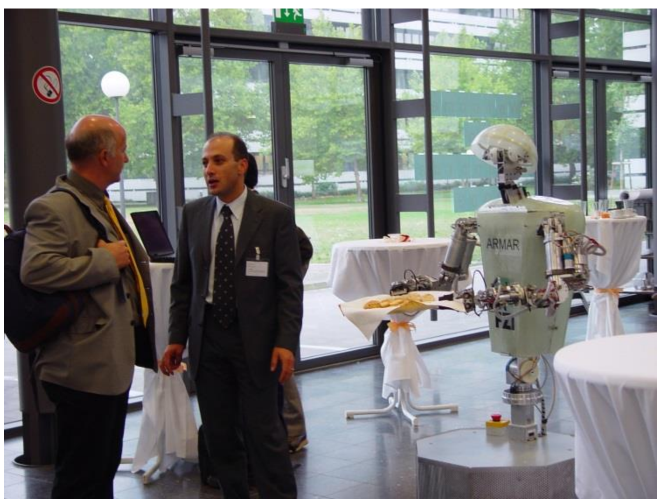



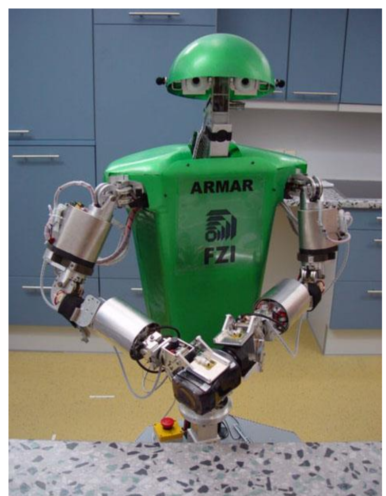




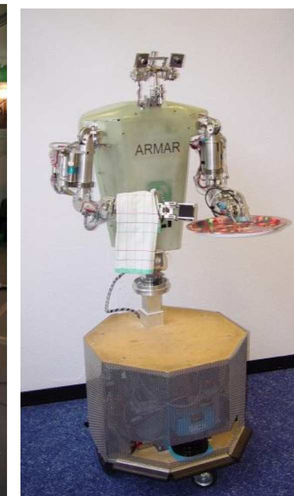

ARMAR-II

- 2003-2007



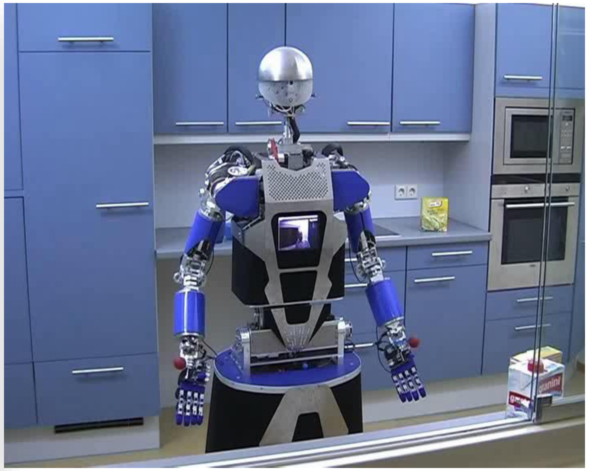
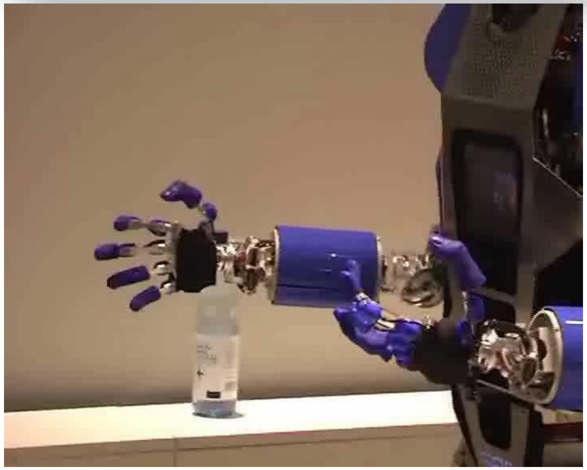






ARMAR-IIIa and ARMAR-IIIb (2006 – today)

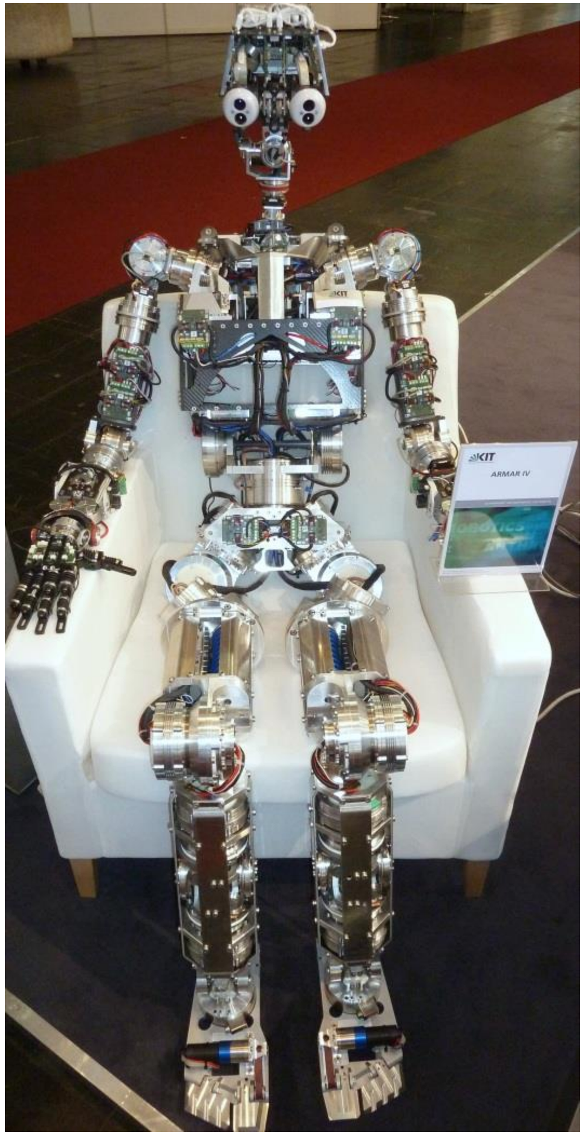
- 7 DOF head with foveated vision
  - 2 cameras in each eye
  - 6 microphones
- 7-DOF arms
  - Position, velocity and torque sensors
  - 6D FT-Sensors
  - Sensitive Skin
- 8-DOF Hands
  - Pneumatic actuators
  - Weight 250g
  - Holding force 2,5 kg
- 3 DOF torso
  - 2 Embedded PCs
  - 10 DSP/FPGA Units
- Holonomic mobile platform
  - 3 laser scanner
  - 3 Embedded PCs
  - 2 Batteries
- Weight: 150 kg

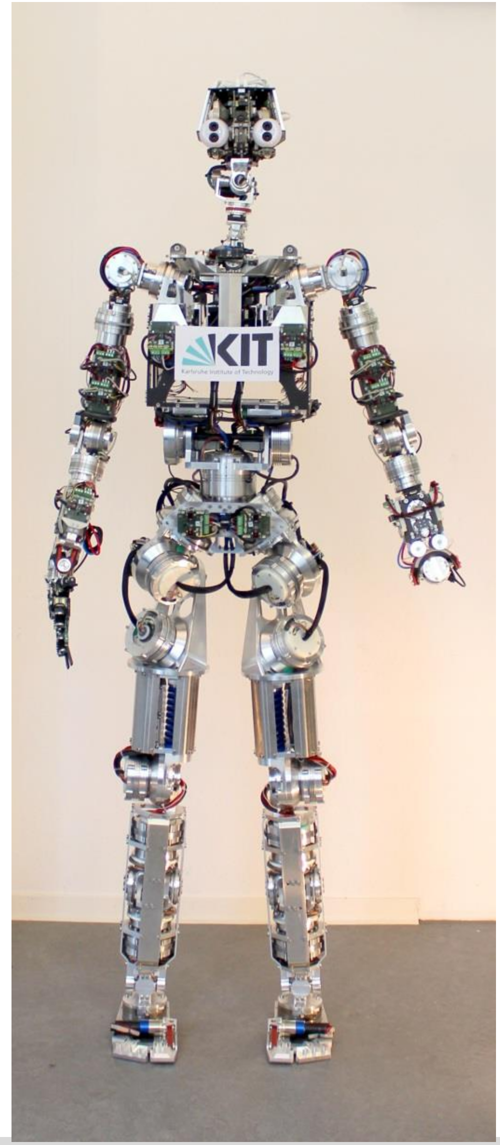




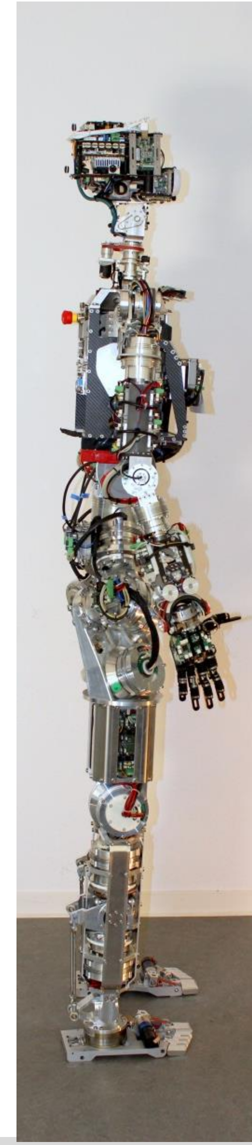

Fully integrated humanoid system

ARMAR-IV (2011 - today)

- 63 DOF
- 170 cm
- 70 kg
- Torque-controlled!







KIT Karlsruhe Institute of Technology

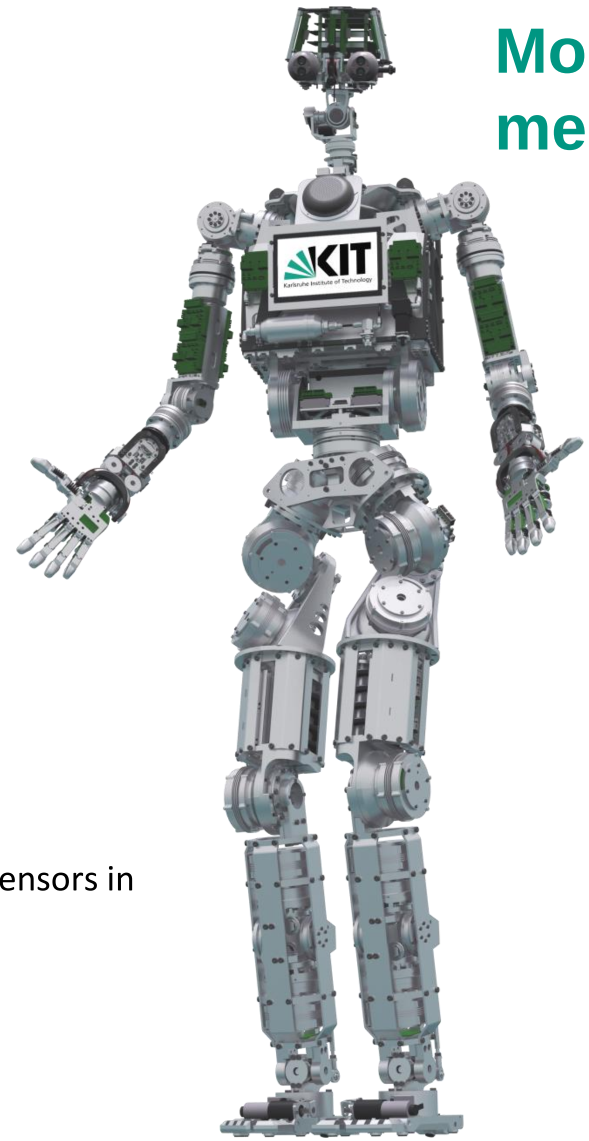
H2T

ARMAR-IV: Mechano-Informatics

- Torque controlled
- 3 on-board embedded PCs
- 76 Microcontroller
- 6 CAN Buses

- 63 DOF
  - 41 electrically-driven
  - 22 pneumatically-driven (Hand)

- 238 Sensors
  - 4 Cameras
  - 6 Microphones
  - 4 6D-force-torque sensors
  - 2 IMUs
  - 128 position (incremental and absolute), torque and temperature sensors in arm, leg and hip joints
  - 18 position (incremental and absolute) sensors in head joints
  - 14 load cells in the feet
  - 22 encoders in hand joints
  - 20 pressure sensors in hand actuators
  - …



More than mechatronics

ARMAR-IV

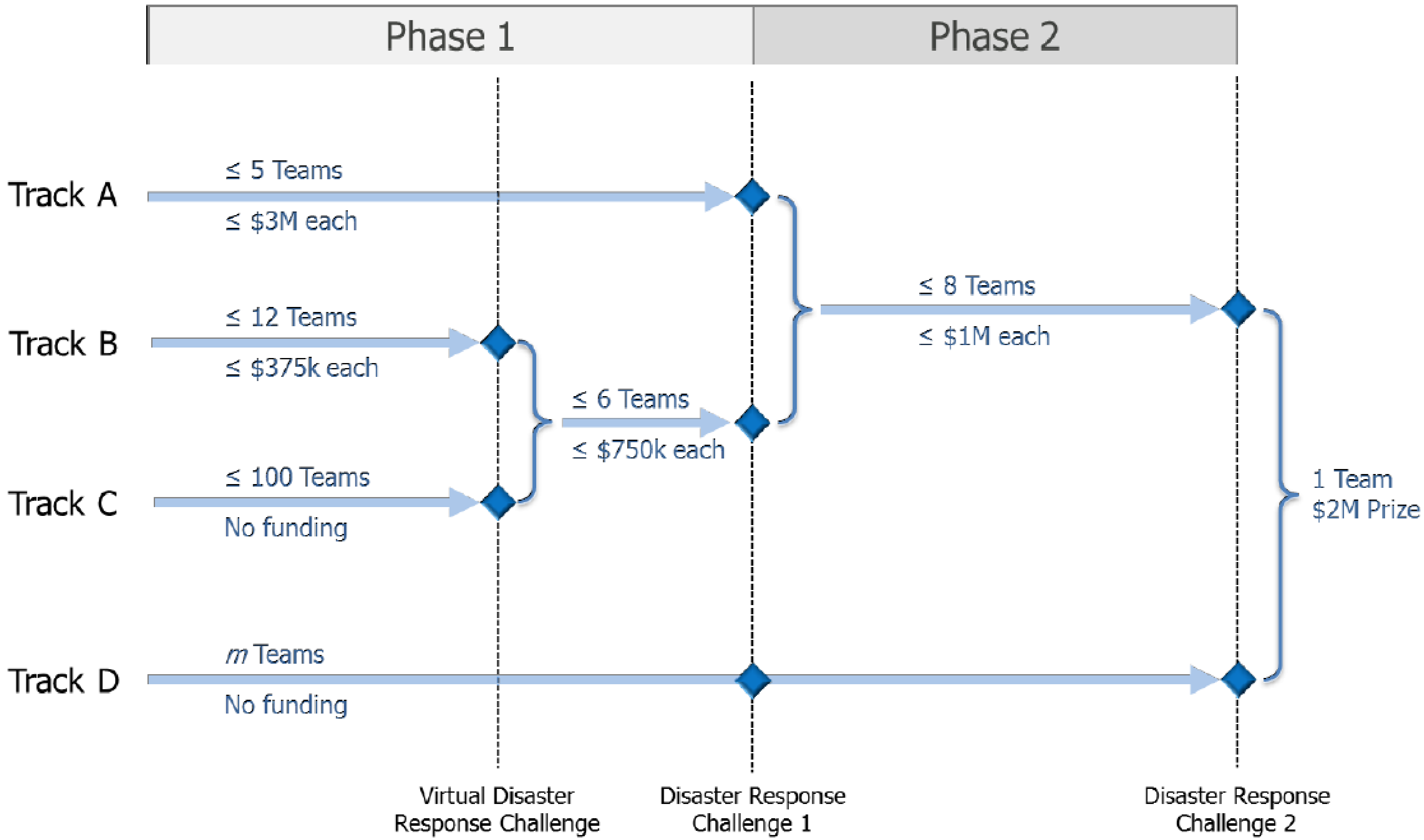
made@KIT

70 kg

170 cm

DRC - DARPA ROBOTICS CHALLENGE

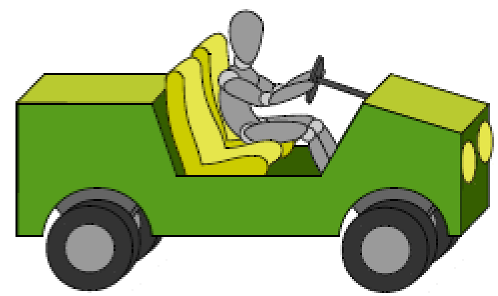
DRC

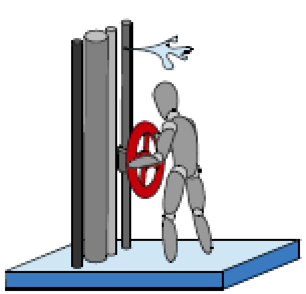


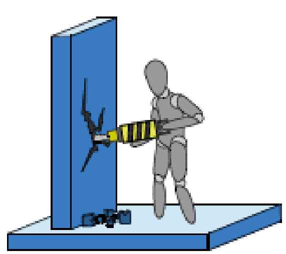
Phase 1
Phase 2
Track A
≤ 5 Teams
≤ $3M each
Track B
≤ 12 Teams
≤ $375k each
Track C
≤ 100 Teams
No funding
Track D
m Teams
No funding
≤ 6 Teams
≤ $750k each
≤ 8 Teams
≤ $1M each
1 Team
$2M Prize
Virtual Disaster
Response Challenge
Disaster Response
Challenge 1
Disaster Response
Challenge 2

The challenge

- The 8 DRC Tasks
  - Drive a utility vehicle
  - Climb a 60 degree ship ladder
  - Walk through 3 different door types
  - Walk over a series of obstacles
  - Clear wood and metal debris
  - Turn on a drill and cut an opening in a wall
  - Mate a hose to a spigot
  - Turn 3 different industrial valves







Overview of teams of phase 2

- **TARTAN RESCUE**
- TEAM AERO (Japan)
- TEAM AIST-NEDO (Japan)
- TEAM DRC-HUBO AT UNLV (USA)
- TEAM GRIT (USA)
- TEAM HECTOR (Darmstadt, Germany)
- TEAM HKU (Hong Kong)
- TEAM HRP2-TOKYO
- **TEAM IHMC ROBOTICS**
- TEAM INTELLIGENT PIONEER (China)
- TEAM KAIST (South Korea)
- **TEAM MIT**
- TEAM NEDO-HYDRA (Japan)
- TEAM NEDO-JSK (Japan)
- TEAM NIMBRO RESCUE (Bonn, Germany)
- **TEAM ROBOSIMIAN**
- TEAM ROBOTIS (South Korea)
- TEAM SNU (South Korea)
- **TEAM THOR**
- **TEAM TRAC LABS**
- **TEAM TROOPER**
- TEAM VALOR (USA)
- **TEAM VIGIR**
- TEAM WALK-MAN (Italy)
- TEAM WPI-CMU (USA)

Bold: 8 finalists, DARPA funded (Tracks A and B)

DRC

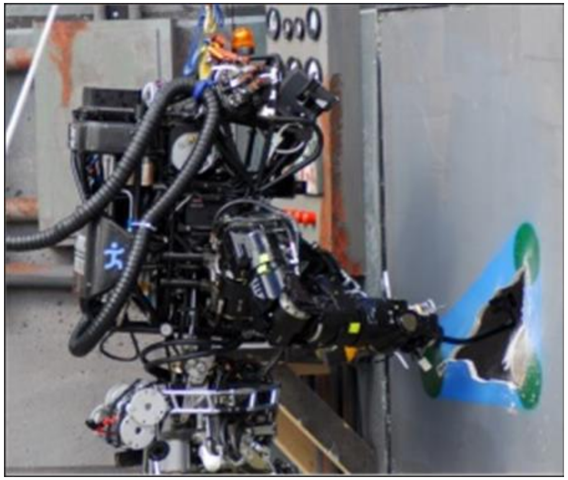
- The DRC finals on June 5-6, 2015 at Fairplex in Pomona, California.
- The event requires robots to attempt a circuit of consecutive physical tasks, with degraded communications between the robots and their operators
- 25 of the top robotics organizations in the world will gather to compete for $3.5 million in prizes as they attempt a simulated disaster-response course.

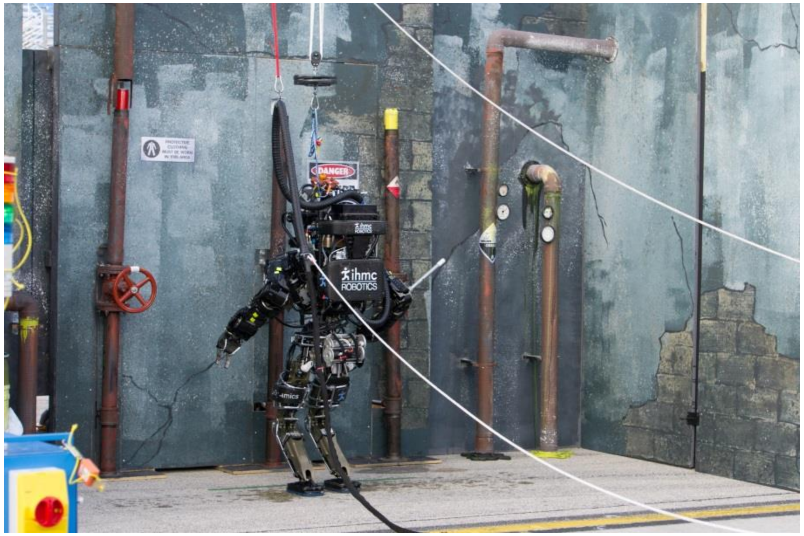
Winners

Position	Team	Final Score	Time (min)
1	TEAM KAIST	8	44:28
2	TEAM IHMC ROBOTICS	8	50:26
3	TARTAN RESCUE	8	55:15
4	TEAM NIMBRO RESCUE	7	34:00
5	TEAM ROBOSIMIAN	7	47:59
6	TEAM MIT	7	50:25
7	TEAM WPI-CMU	7	56:06
8	TEAM DRC-HUBO AT UNLV	6	57:41
9	TEAM TRACLABS	5	49:00
10	TEAM AIST-NEDO	5	52:30

IHMC Robotics

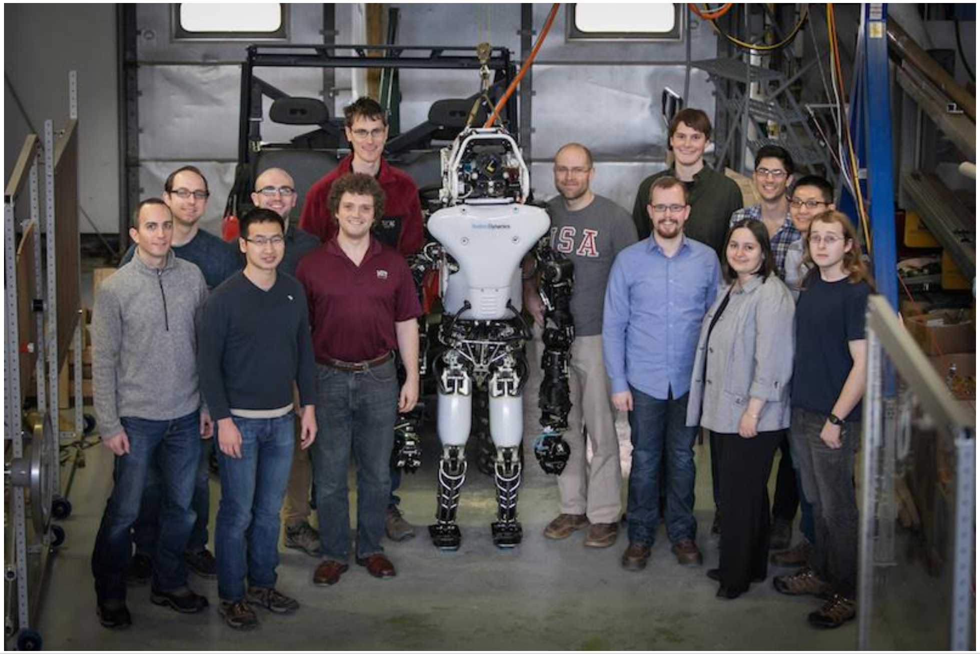
- Robot: ATLAS-Ian
- Florida Institute for Human & Machine Cognition
- Team leaders:
  - Jerry Pratt
  - Matt Johnson

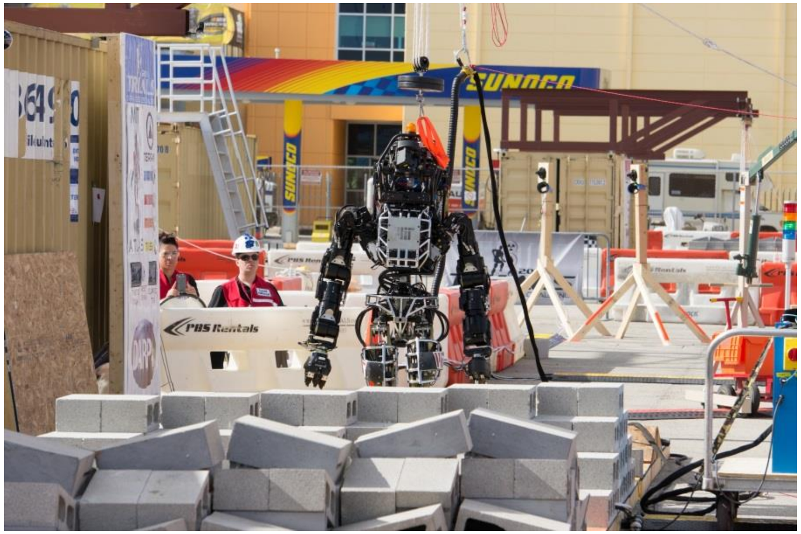




MIT

- Robot: Atlas - Helios
- MIT, Cambridge, MA
- Team leader: Russ Tedrake
- **Sub Leads:** Maurice Fallon (perception), Scott Kuindersma (planning and control), Pat Marion (interface)

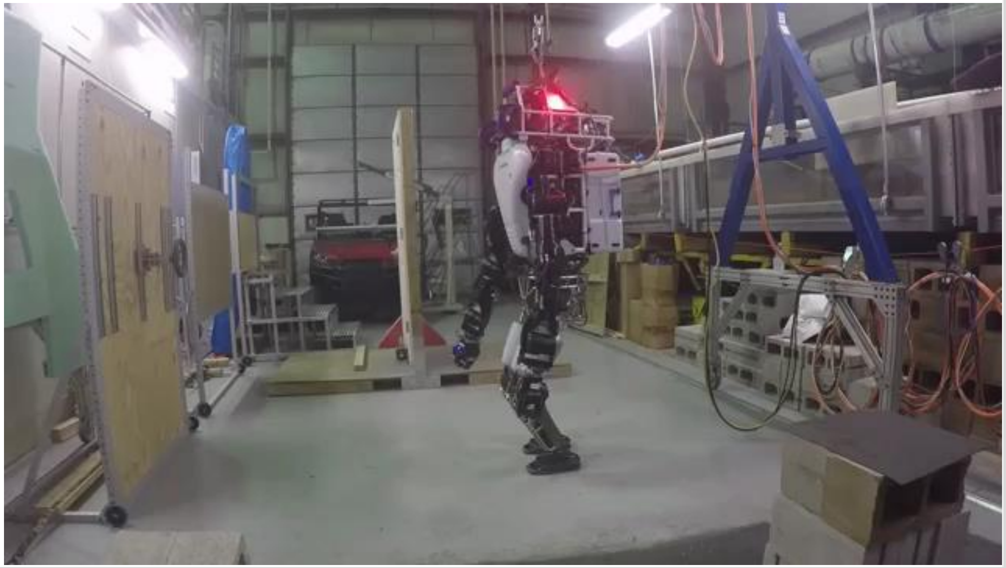




MIT

Whole-body grasping

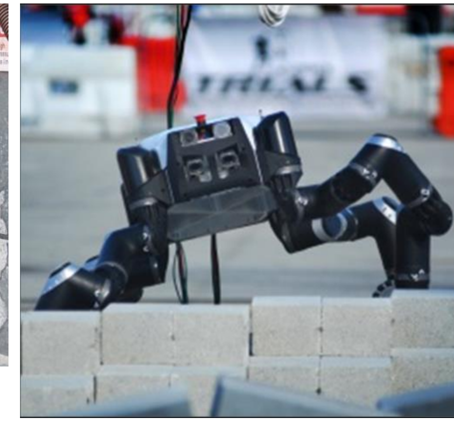
Fast walking

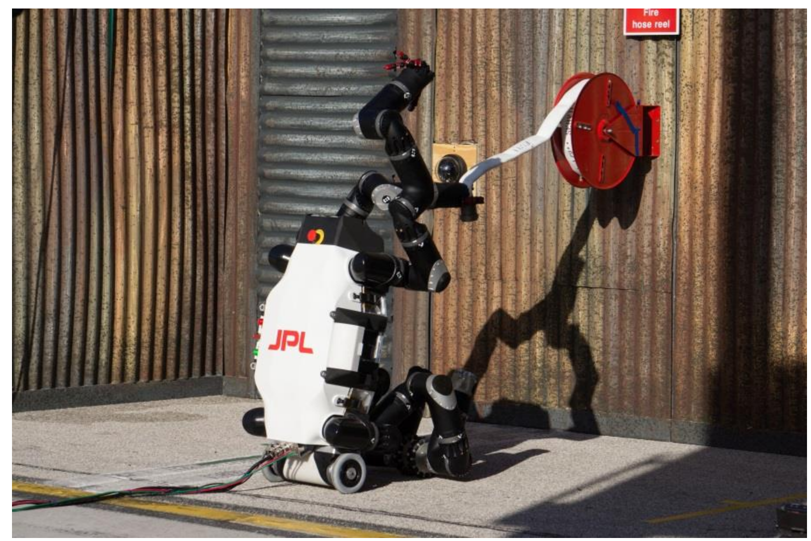


RoboSimian

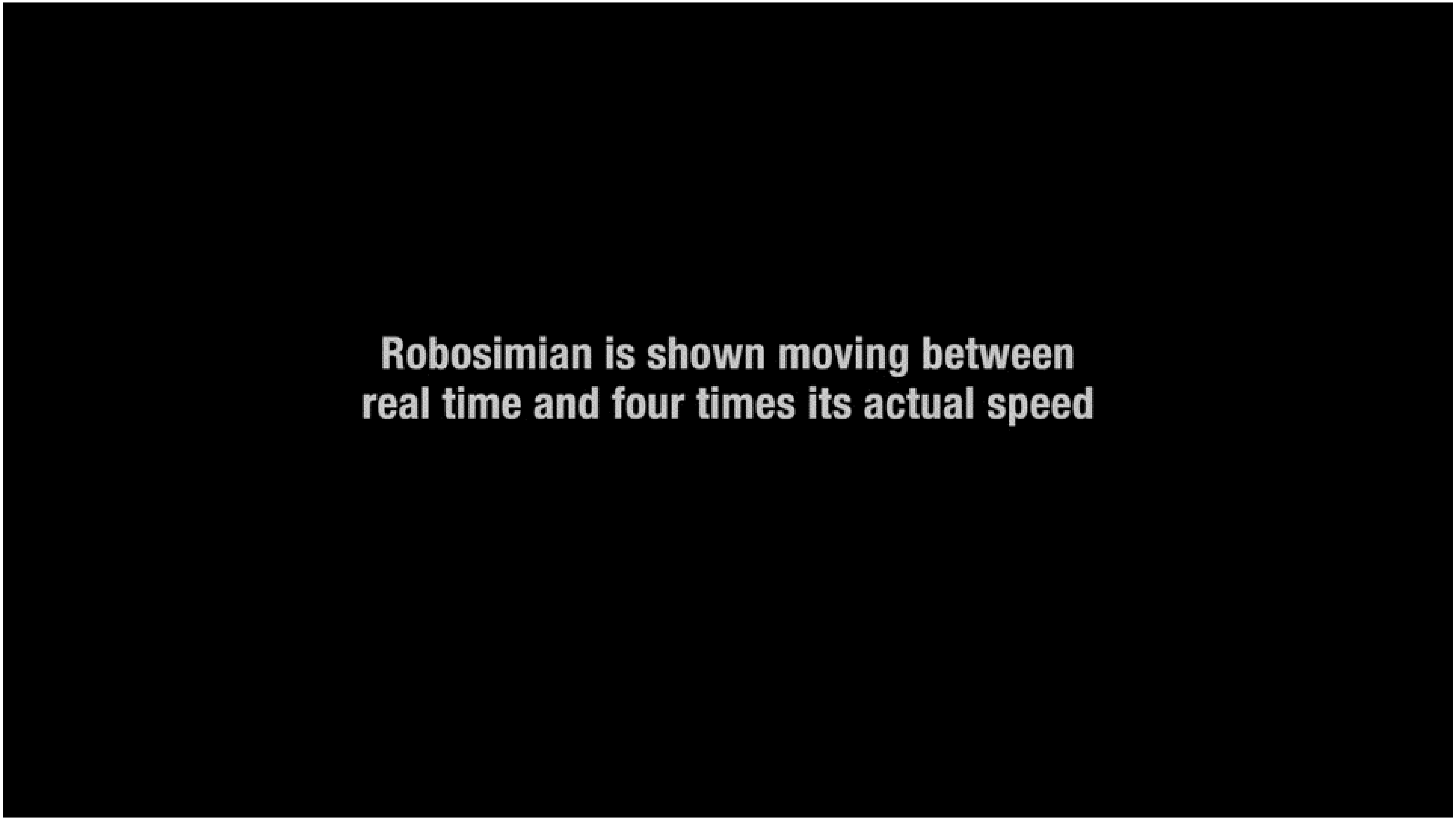
- Robot: RoboSimian
- NASA Jet Propulsion Lab

- Height: 164cm in bipedal pose
- Weight: 108kg
- Wingspan: 221cm





RoboSimian

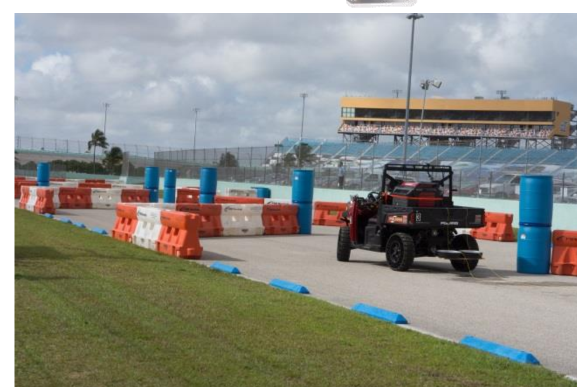

Robosimian is shown moving between
real time and four times its actual speed

Tartan Rescue

- Robot: CHIMP
  - CHIMP is a recursive acronym: „CMU Highly Intelligent Mobile Platform“
- Carnegie Mellon University Pittsburgh
- Height: 5 feet and 2 inches
- Weight: 200kg
- Wingspan: ~10 feet

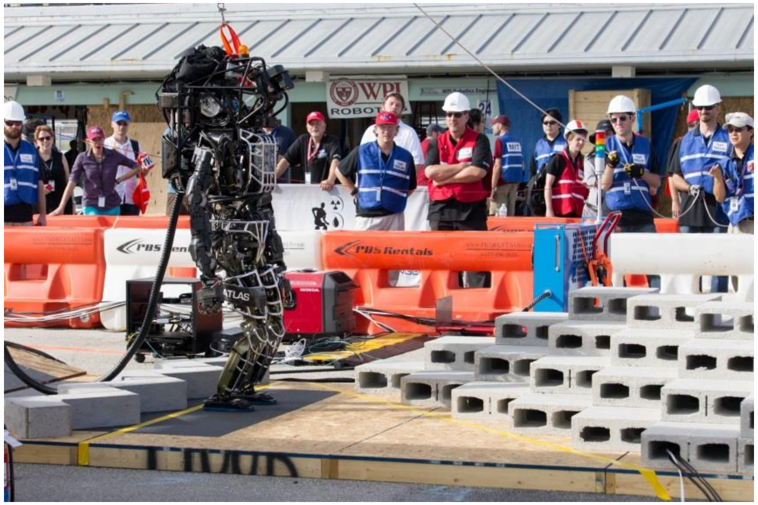
Team THOR

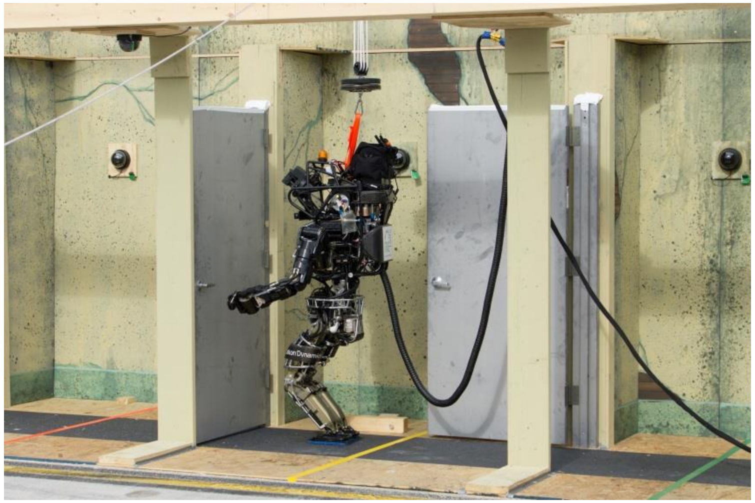
- Robot: THOR-OP
  - THOR = „Tactile Hazardous Operations Robot“
- Virginia Tech
- Team leader: Dennis Hong
- Height: 178cm
- Weight: 65kg
- Wingspan: 2.08m



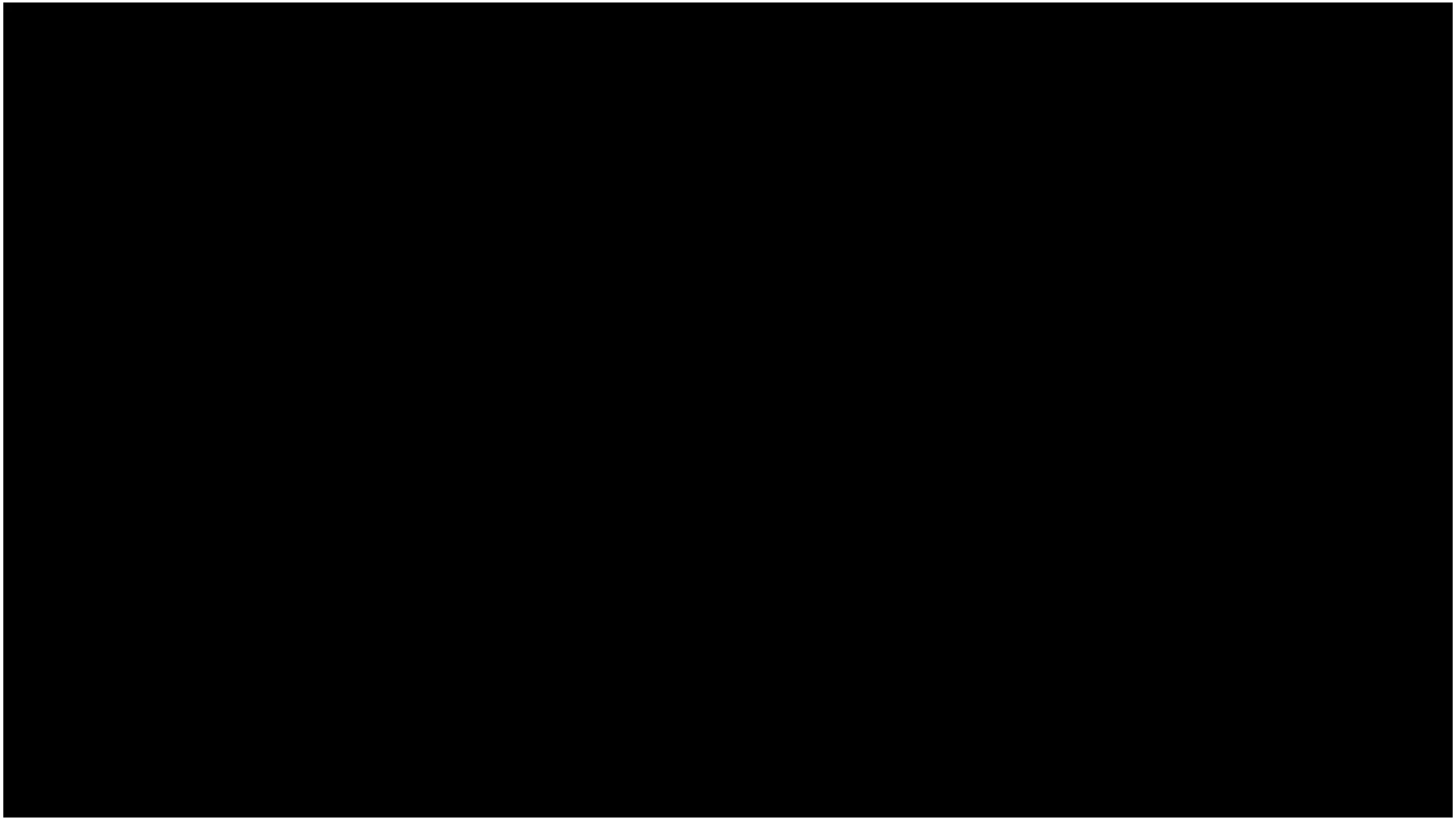
Team TRACLabs

- Robot: Atlas - Hercules
- Webster, Texas
- Team leader: David Kortenkamp





Team TRACLabs

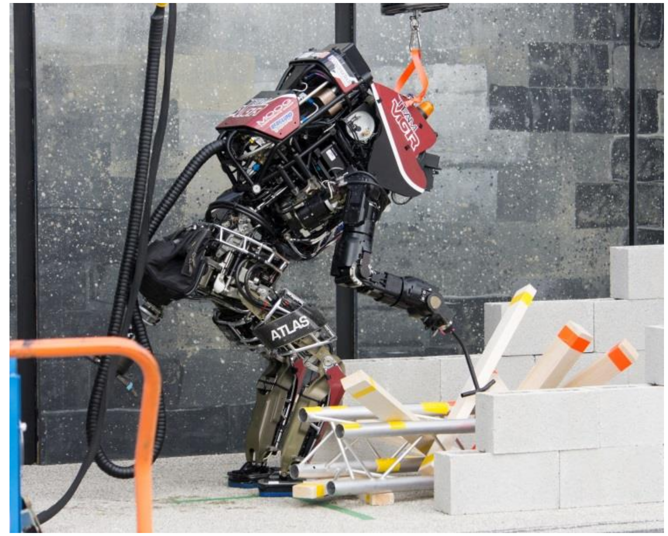


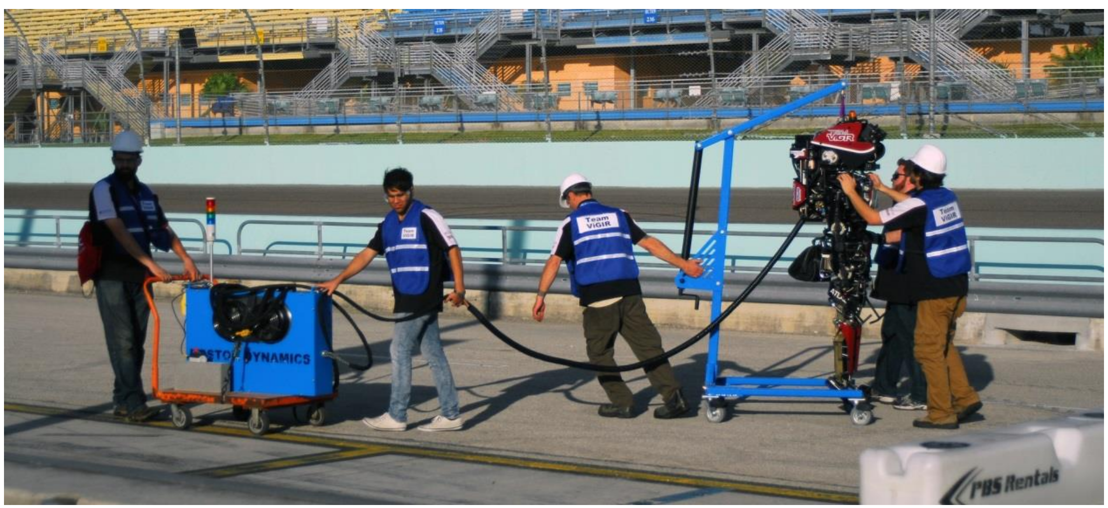
Team TROOPER

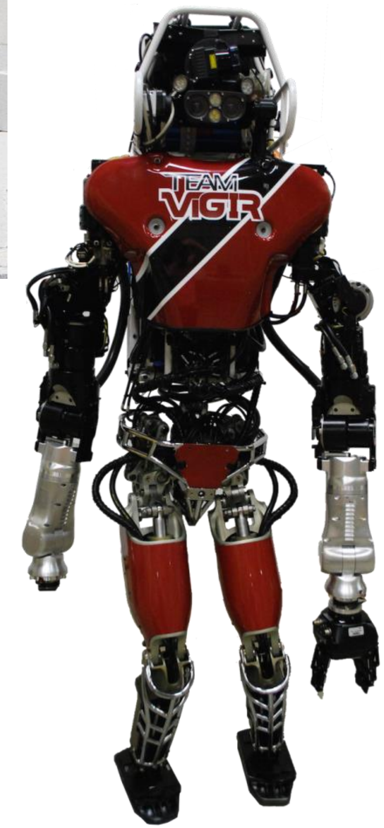
- Robot: Atlas - Leo
- Cherry Hill, NJ - Troy, NY - Philadelphia, PA
- Cooperation of:
  - Lockheed Martin
  - University of Pennsylvania
  - Rensselaer Polytechnic Institute

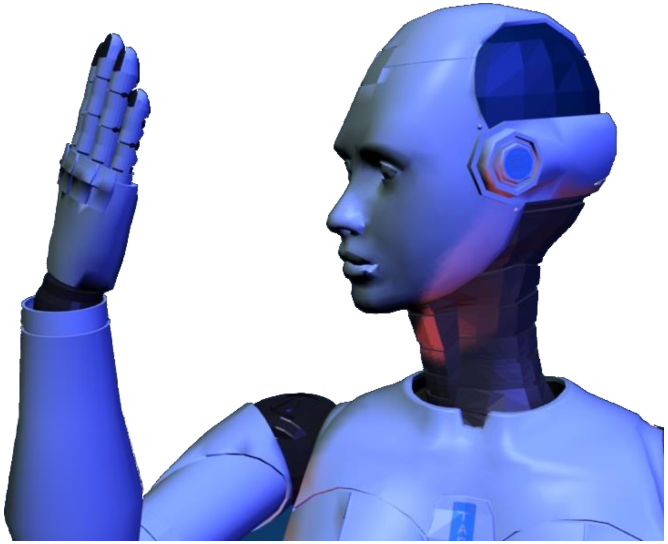
Team ViGIR

- Robot: Florian
- Cooperation of:
  - TORC Robotics
  - Virginia Tech
  - TU Darmstadt, Germany
  - Oregon State University



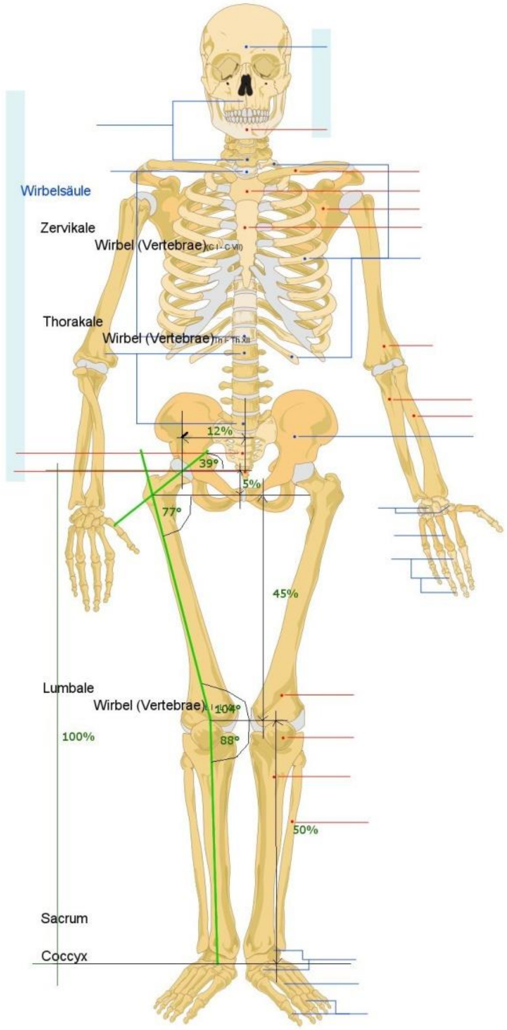


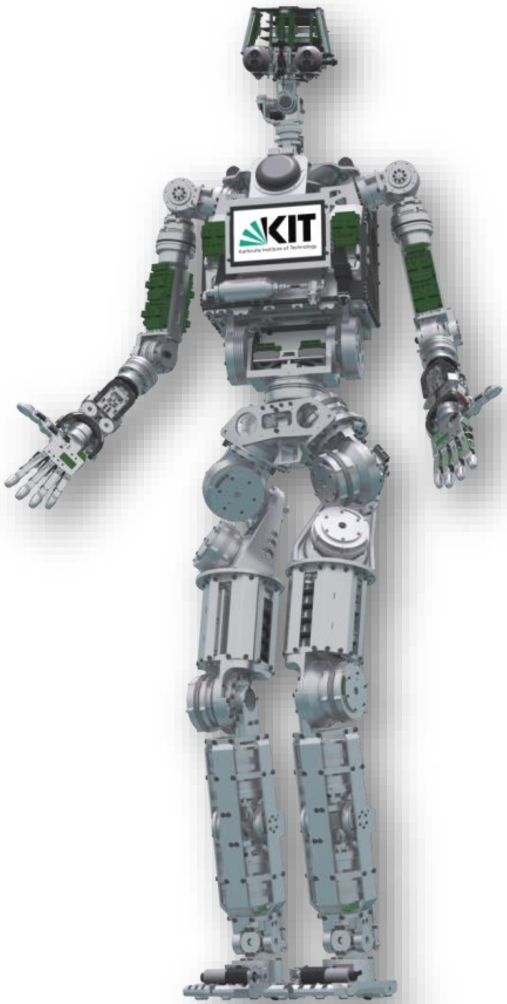




Human Body and humanoid models

From human body to humanoid

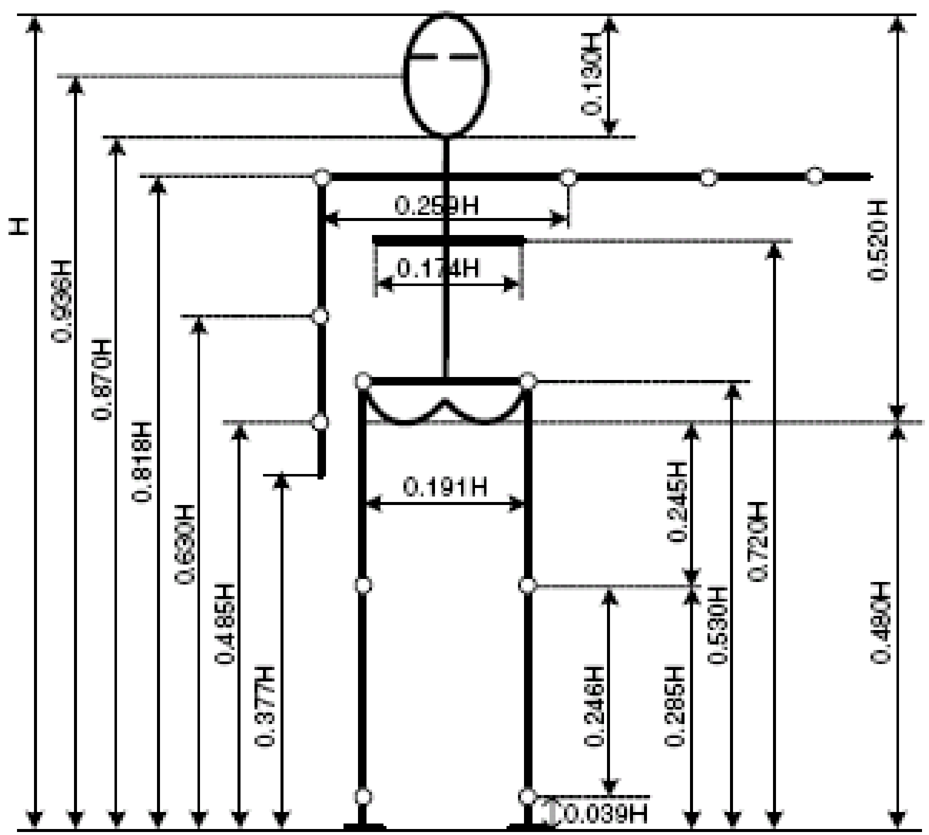




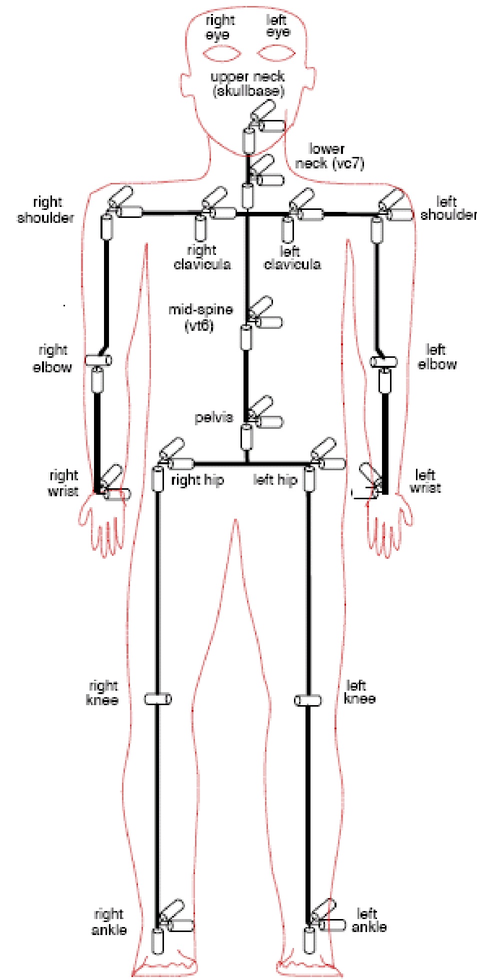
Models of human body for …

- Human factors engineering
  - Ergonomics
  - Work space design
  - Driver's cab
- Computer graphics
  - Animation
  - Entertainment
  - Visualization
- Medical application
  - Rehabilitation
  - Human anatomy http://www.visiblebody.com
- Robotics
  - Design of anthropomorphic robots e.g. humanoids
  - Design of assistant systems (prosthesis and orthoses)

Human body model



D.A. Winter, Biomechanics and Motor Control of Human Movement, John Wiley & Sons Inc. 1990



P. Azad, T. Asfour, and R. Dillmann, “Toward an Unified Representation for Imitation of Human Motion on Humanoids,” in IEEE International Conference on Robotics and Automation, Rome, Italy, April 2007.

Master Motor Map (MMM) – Motivation

- Design of humanoid robots

  → models of body parts are needed

- Various human motion capture systems action recognition systems, imitation systems, visualization modules, and robot systems for reproduction

  → Unified representation is needed!

Master Motor Map (MMM)

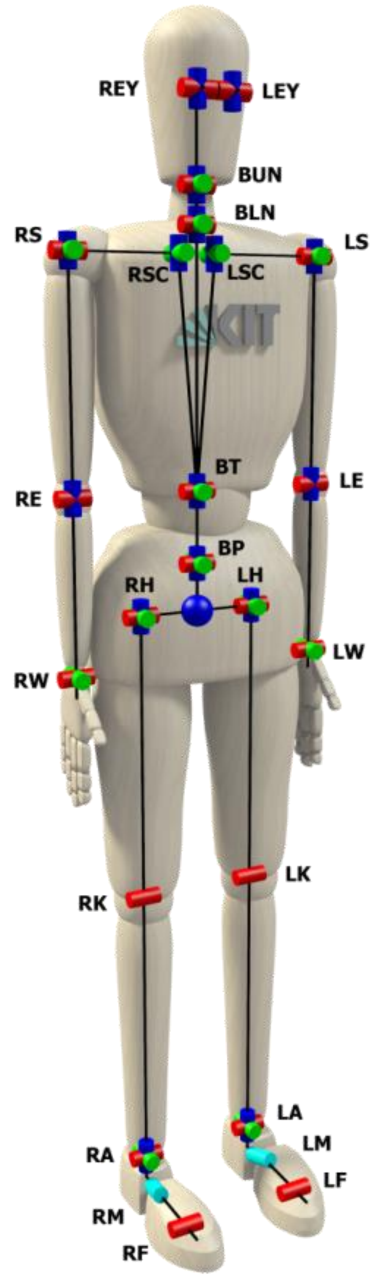
Red: relevant for the exam

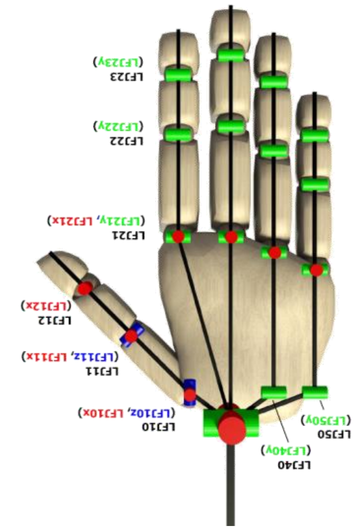
- Reference model of the human body
  - For humanoid robot design
  - Imitation of human actions
  - Action recognition
  - Visualisation of human movements
- Interfaces and data structures for the transfer of motor knowledge between different embodiments

1. *C. Mandery, Ö. Terlemez, M. Do, N. Vahrenkamp and T. Asfour, **Unifying Representations and Large-Scale Whole-Body Motion Databases for Studying Human Motion**, IEEE Transactions on Robotics, Vol. 32, No. 4, pp. 796 - 809, August, 2016*
2. *O. Terlemez, S. Ulbrich, C. Mandery, M. Do, N. Vahrenkamp and T. Asfour, **Master Motor Map (MMM) – Framework and Toolkit for Capturing, Representing, and Reproducing Human Motion on Humanoid Robots**, IEEE/RAS International Conference on Humanoid Robots (Humanoids), 2014*
3. *C. Mandery, O. Terlemez, M. Do, N. Vahrenkamp and T. Asfour, **The KIT Whole-Body Human Motion Database**, International Conference on Advanced Robotics (ICAR), 2015*
4. *S. Gärtner, M. Do, C. Simonidis, T. Asfour, W. Seemann and R. Dillmann, **Generation of Human-like Motion for Humanoid Robots Based on Marker-based Motion Capture Data**, 41th International Symposium on Robotics (ISR), pp. 1 - 8, 2010*
5. *Pedram Azad, Tamim Asfour and Ruediger Dillmann. **Toward an Unified Representation for Imitation of Human Motion on Humanoids**. IEEE International Conference on Robotics and Automation, 2007*

Master Motor Map (MMM)

- Reference model of the human body
  - Kinematic model: joints and segment lengths
  - Dynamic model: segment mass, center of mass and moments of inertia
  - Statistic/anthropomorphic model: Segment properties (e.g. length, mass etc) defined as a function (regression) of global parameters (e.g. body height, weight)
  - 104 DoFs





Statistic/ Anthropomorphic Model

- Body segment properties (e.g. length, mass etc) are defined as a function (regression) of certain global parameters (e.g. body height, weight etc.)

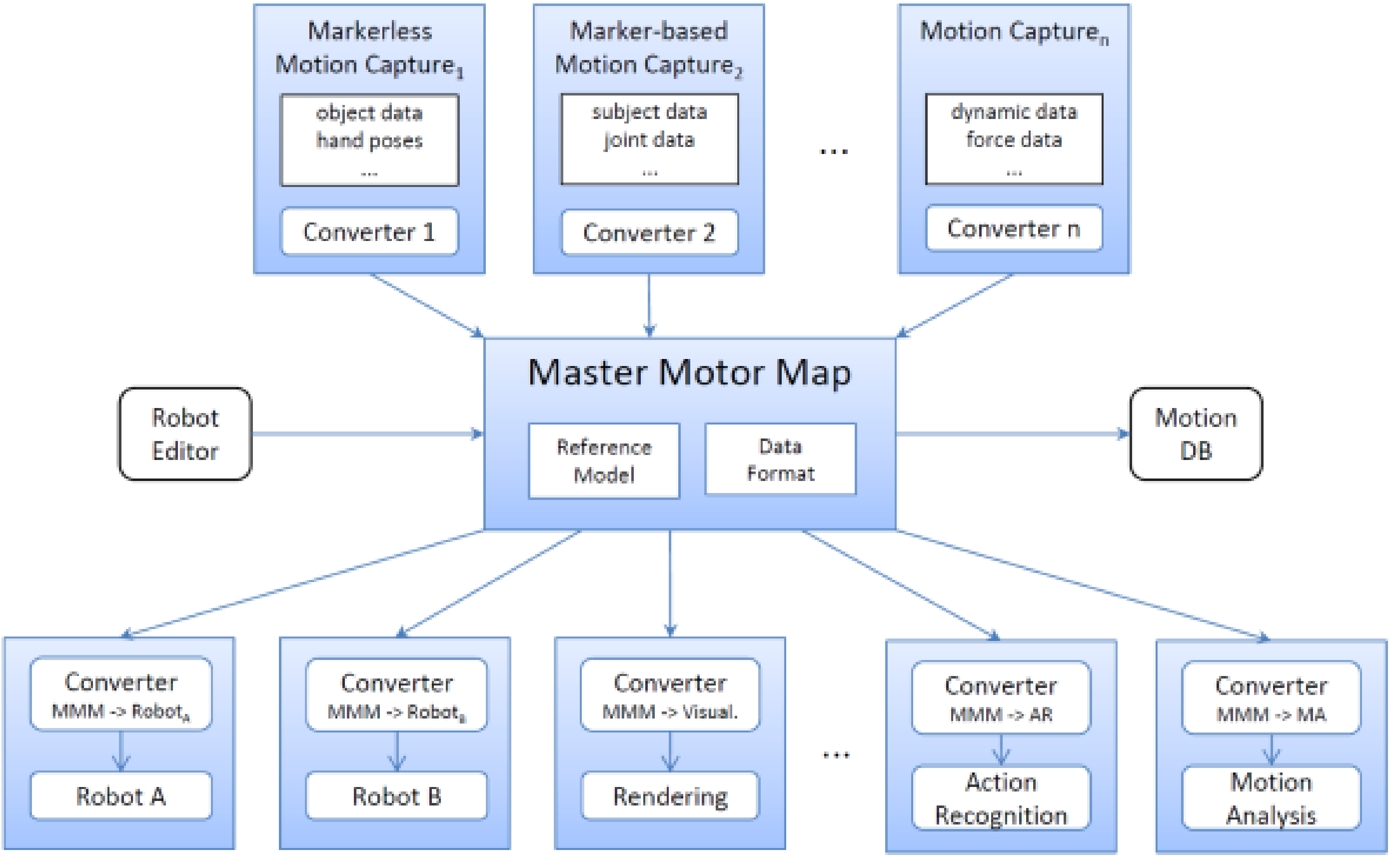
- Models have been discovered and verified by various researchers (see for example de Leva 1996, Winter 2005, Pronost et al., 2006)

D.A. Winter, Biomechanics and Motor Control of Human Movement, John Wiley & Sons Inc. 1990

P. de Leva, “Adjustments to zatsiorsky-seluyanov’s segment inertia parameters,” J. of Biomechanics, vol. 29, no. 9, pp. 1223 – 1230,1996.

The Master Motor Map (MMM)

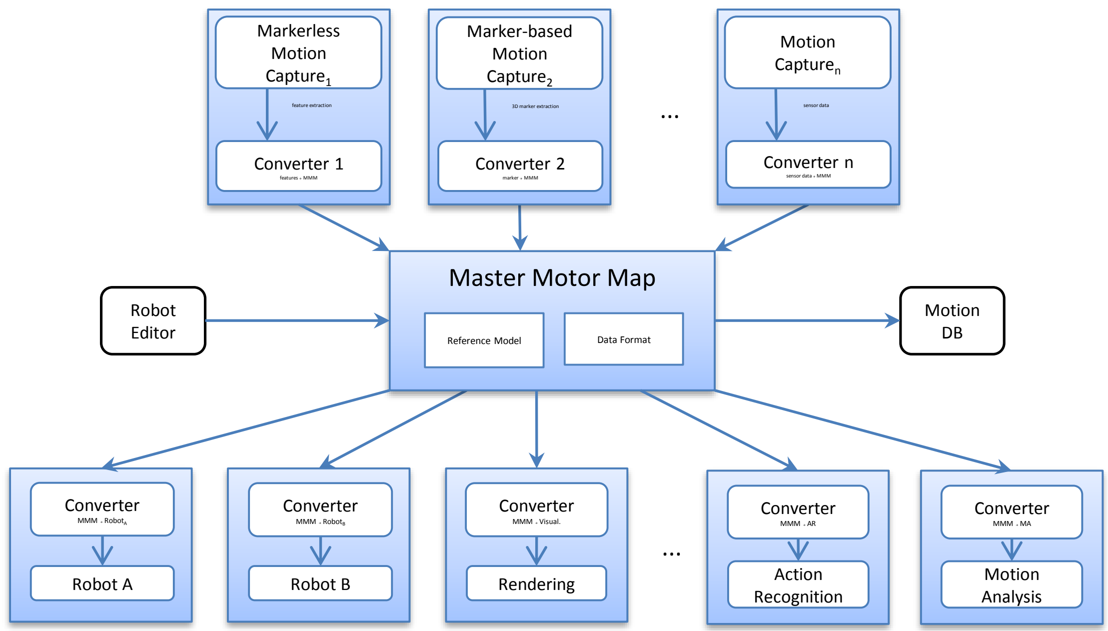
- **Unifying framework** for capturing, representation, visualization and whole body human motion and mapping/converting to different embodiments



T-RO 2016

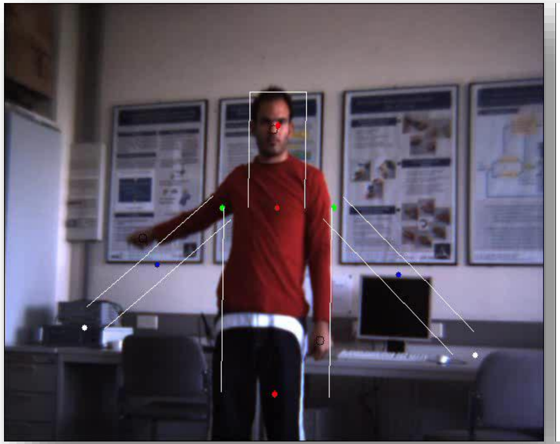
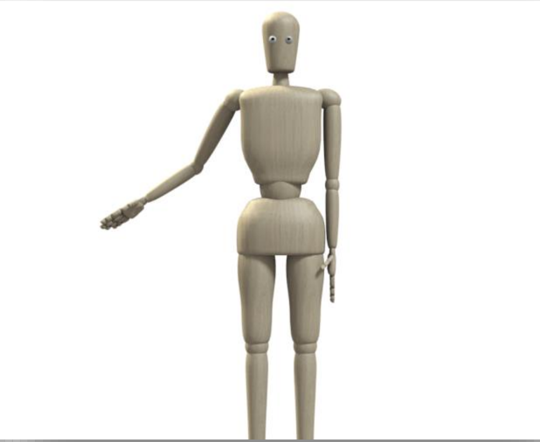
Master Motor Map (MMM)

- Replacement of any module (perception, recognition, visualization, reproduction) can be guaranteed by using the MMM as the exchange format
- All perceptive module convert their output to the MMM format
- All recognition and reproduction modules convert the MMM format to their specific internal representation

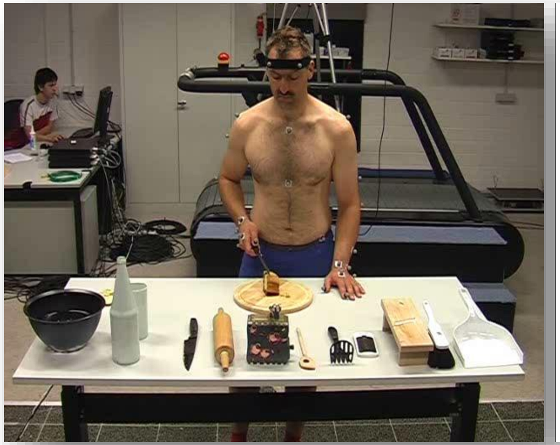
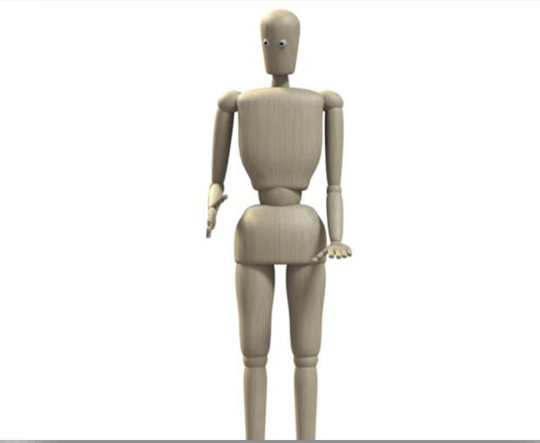


Motion reproduction using MMM

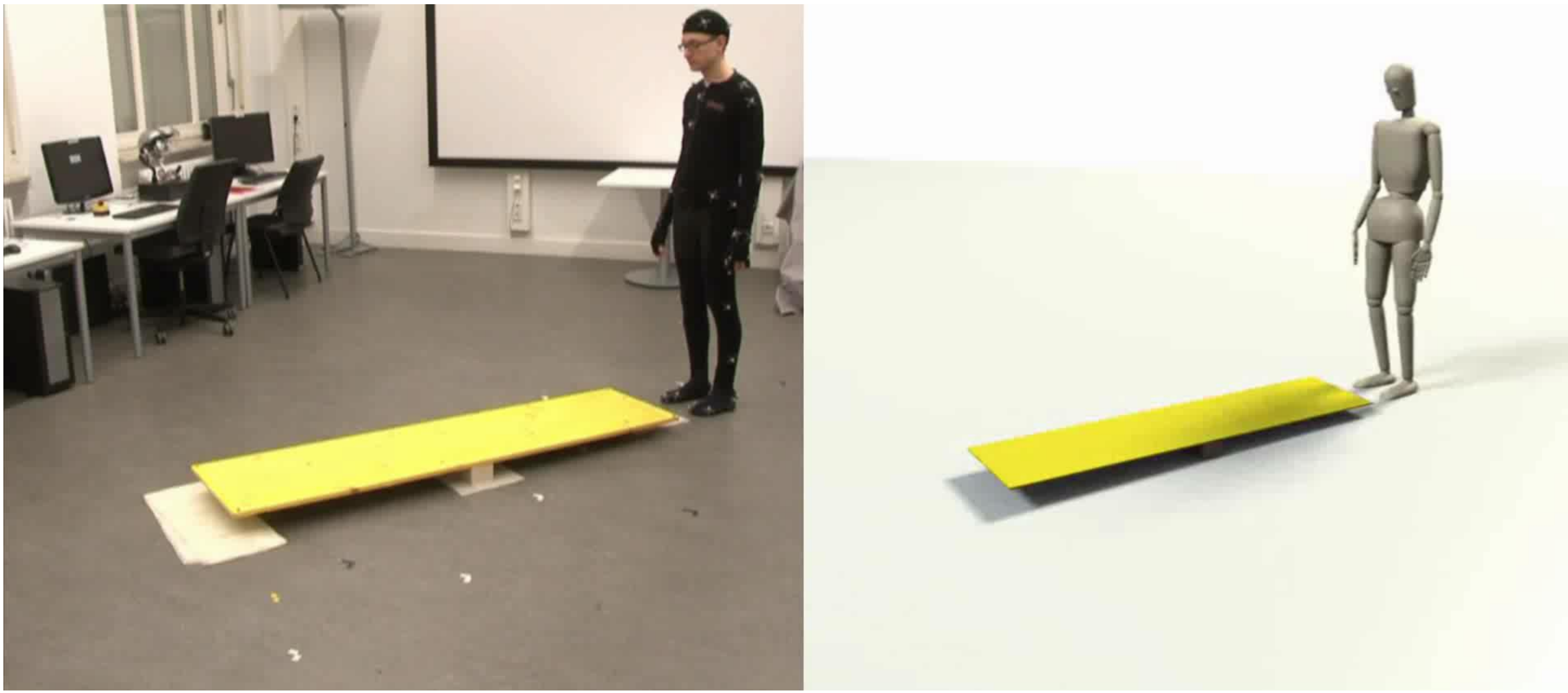
- Data from stereo-based markerless human motion capture system

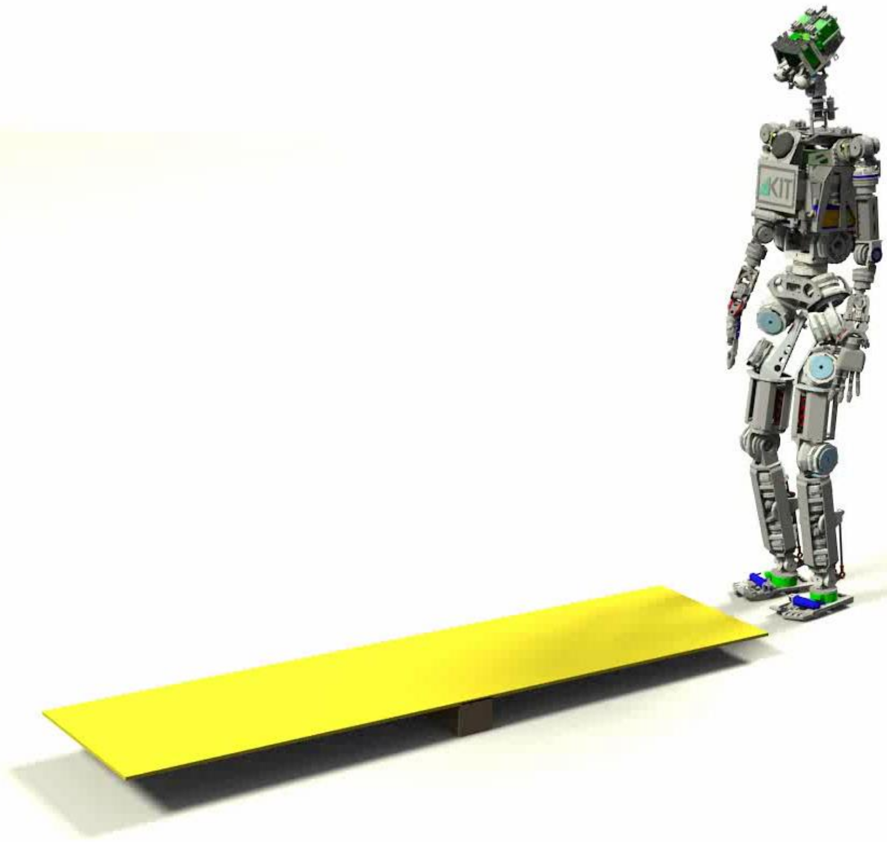
- Data from VICON system (SFB 588)

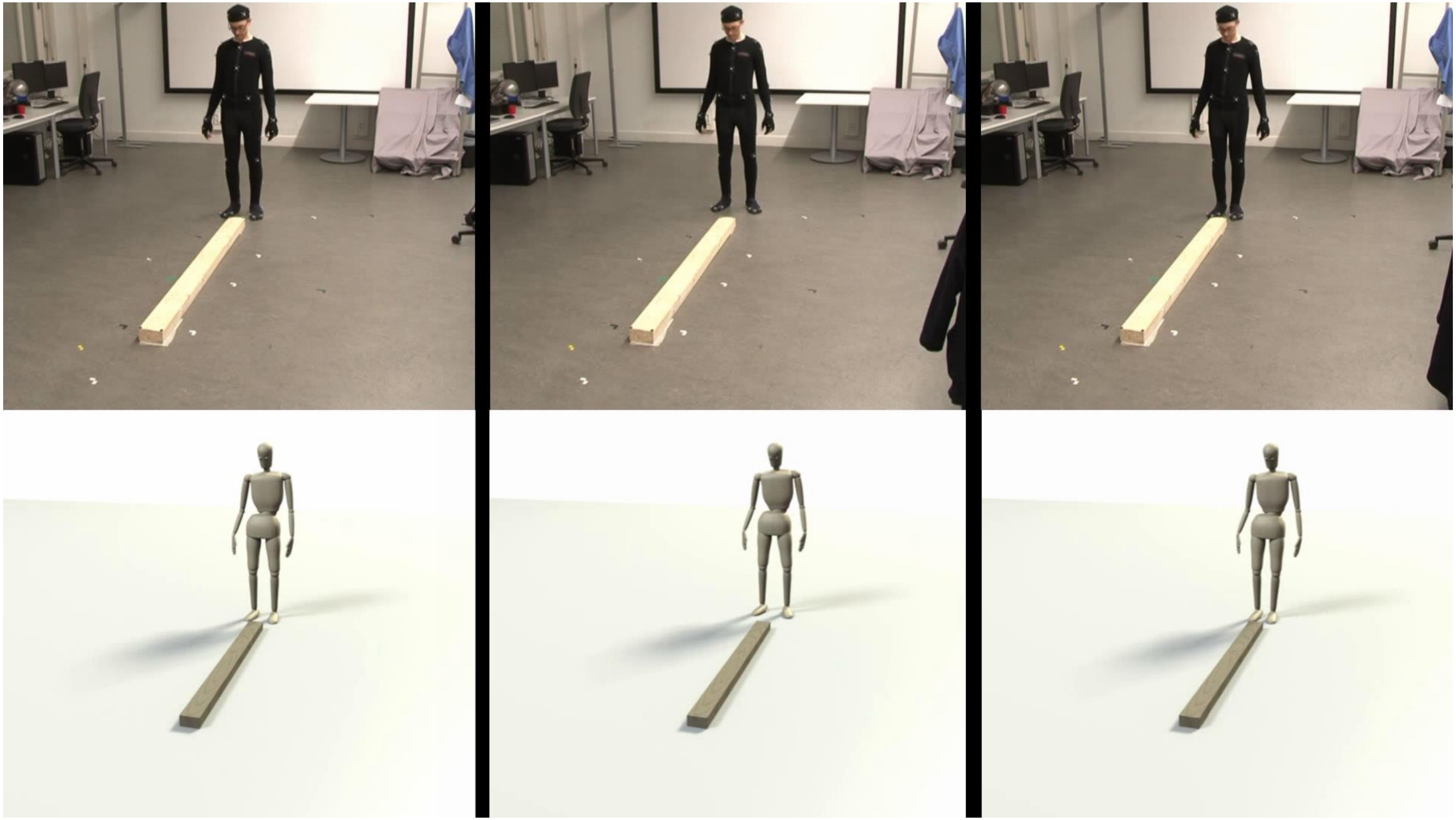
Motion Reproduction using MMM



Motion Reproduction using MMM



Motion Normalization using the MMM (Video)



KIT Human Motion Database

The KIT Whole-Body Human Motion Database

Christian Mandery, Ömer Terlemez, Martin Do,
Nikolaus Vahrenkamp, Tamim Asfour

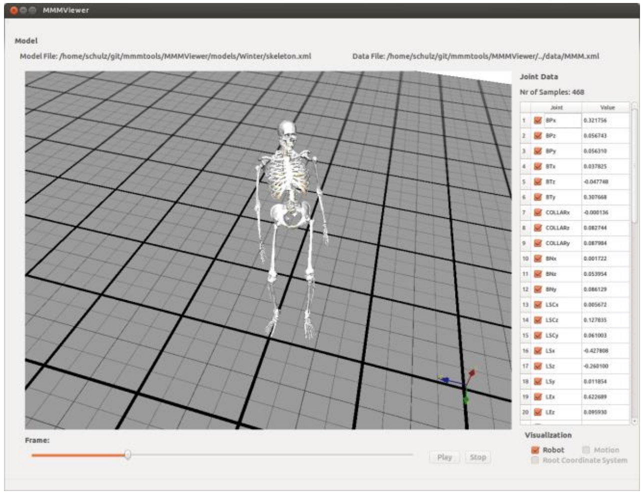
Institute for Anthropomatics and Robotics
Karlsruhe Institute of Technology (KIT), Germany
Mail: mandery@kit.edu, asfour@kit.edu

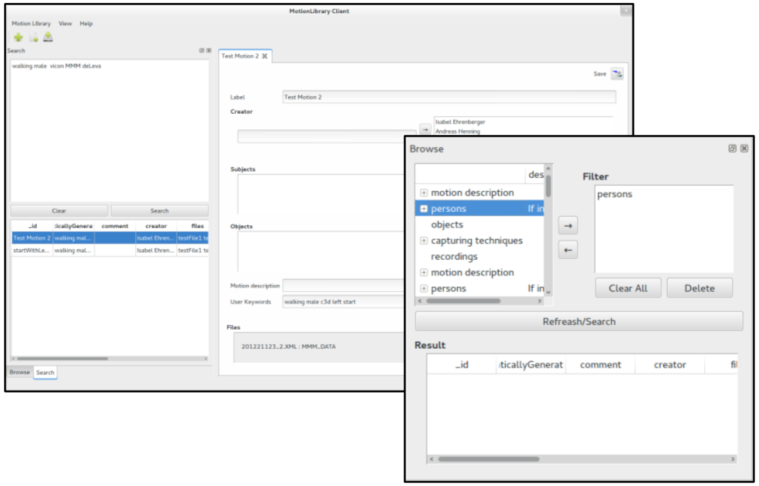
MMM Software and documentation

- MMM Software:
  - https://gitlab.com/mastermotormap/mmmcore
  - https://gitlab.com/mastermotormap/mmmtools
- MMM Dokumentation:
  - http://mmm.humanoids.kit.edu
  - https://motion-database.humanoids.kit.edu/faq
- KIT Whole-Body Motion Database
  - https://motion-database.humanoids.kit.edu

MMM Library & Tools

- **MMM Core**
  - C++ Library
  - I/O, XML, Raw Marker Data, Tools, Conversions
  - No dependencies (just Boost)
- **Mapping / Converter**
  - Vicon -> MMM model
  - MMM -> Robots (ARMAR III, ARMAR IV)
  - MMM -> Other robots (iCub, COMAN, HRP, …)
- **MMM Viewer**
  - 3D Model Viewer
  - MMM / Marker Data
  - Robots, Motions, Contacts, …
- **MMM Database**
  - Server
  - Client/Applications, Search, Web Frontend





Motion Annotation project

- Praxis der Forschung project of Matthias Plappert

  https://motion-annotation.humanoids.kit.edu/

- Your help is appreciated !

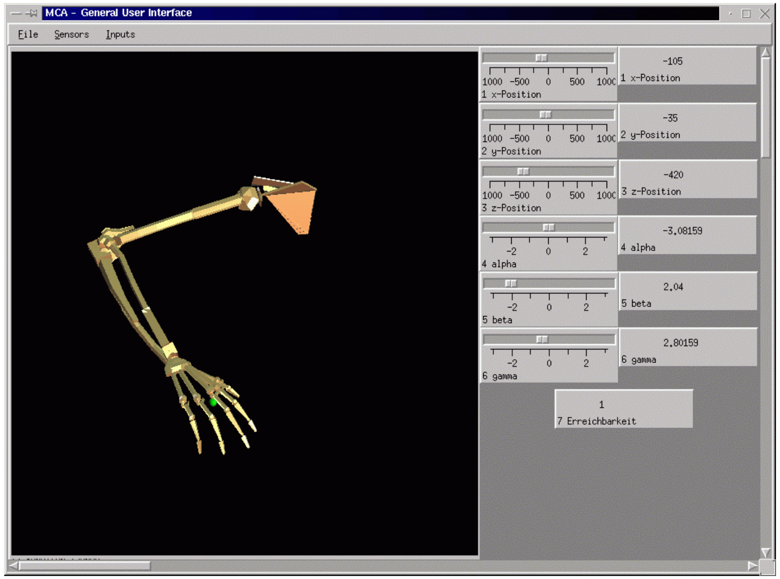
References

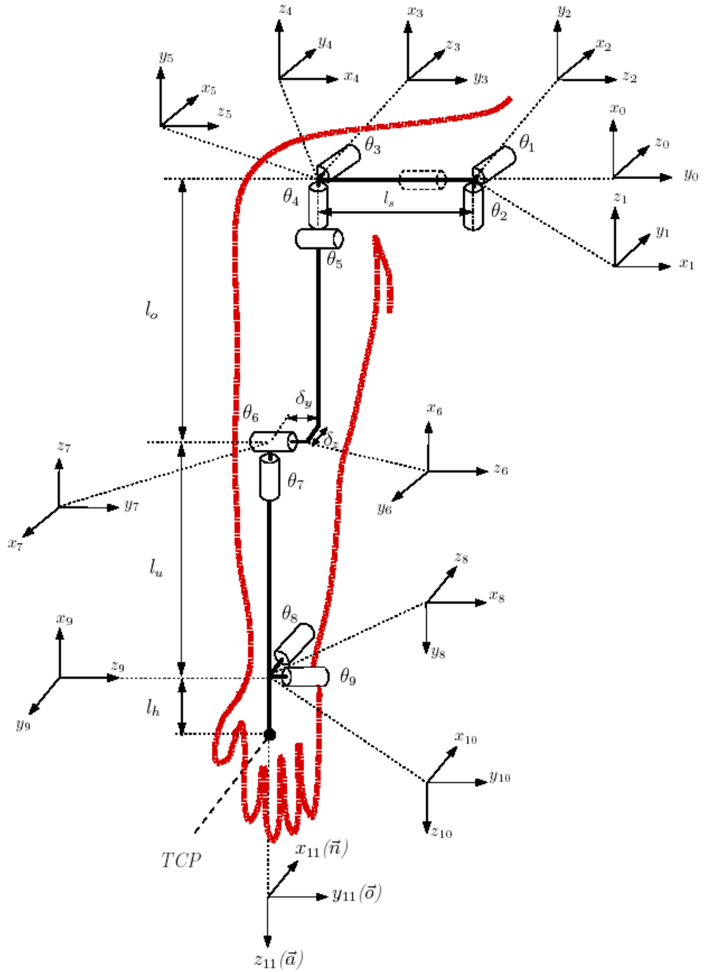
Red: relevant for the exam

- Our previous work on the MMM
  - C. Mandery, Ö. Terlemez, M. Do, N. Vahrenkamp and T. Asfour, **Unifying Representations and Large-Scale Whole-Body Motion Databases for Studying Human Motion**, IEEE Transactions on Robotics, Vol. 32, No. 4, pp. 796 - 809, August, 2016
  - O. Terlemez, S. Ulbrich, C. Mandery, M. Do, N. Vahrenkamp and T. Asfour, **Master Motor Map (MMM) – Framework and Toolkit for Capturing, Representing, and Reproducing Human Motion on Humanoid Robots**, IEEE/RAS International Conference on Humanoid Robots (Humanoids), 2014
  - C. Mandery, O. Terlemez, M. Do, N. Vahrenkamp and T. Asfour, **The KIT Whole-Body Human Motion Database**, International Conference on Advanced Robotics (ICAR), 2015
  - S. Gärtner, M. Do, C. Simonidis, T. Asfour, W. Seemann and R. Dillmann, **Generation of Human-like Motion for Humanoid Robots Based on Marker-based Motion Capture Data**, 41th International Symposium on Robotics (ISR), pp. 1 - 8, 2010
  - Pedram Azad, Tamim Asfour and Ruediger Dillmann. **Toward an Unified Representation for Imitation of Human Motion on Humanoids**. IEEE International Conference on Robotics and Automation, 2007
- Others
  - David A. Winter. **Biomechanics and Motor Control of Human Movement**. John Wiley & Sons, Inc. 2005
  - P. de Leva, **Adjustments to Zatsiorsky-Seluyanov's Segment Inertia Parameters**, J. of Biomechanics, vol. 29, no. 9, pp. 1223 – 1230, 1996.
  - Nicolas Pronost, Georges Dumont. **Validating re-targeted and interpolated locomotions by dynamics-based analysis**. Proceedings of the 4th international conference on Computer graphics and interactive techniques in Australasia and Southeast Asia. 2006
  - Michael Gleicher. **Retargetting Motion to New Characters**. SIGGRAPH 2008

Kinematic model of the human shoulder-arm system

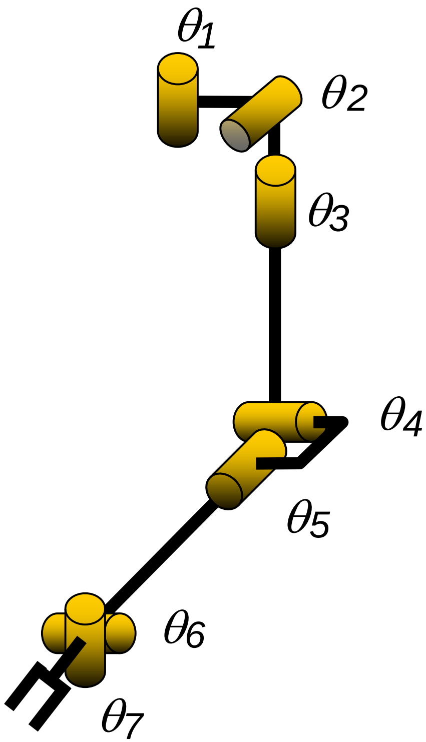
- 9 DOF
  - Shoulder: 5 DOF
  - Elbow: 2 DOF
  - Wrist: 2 DOF



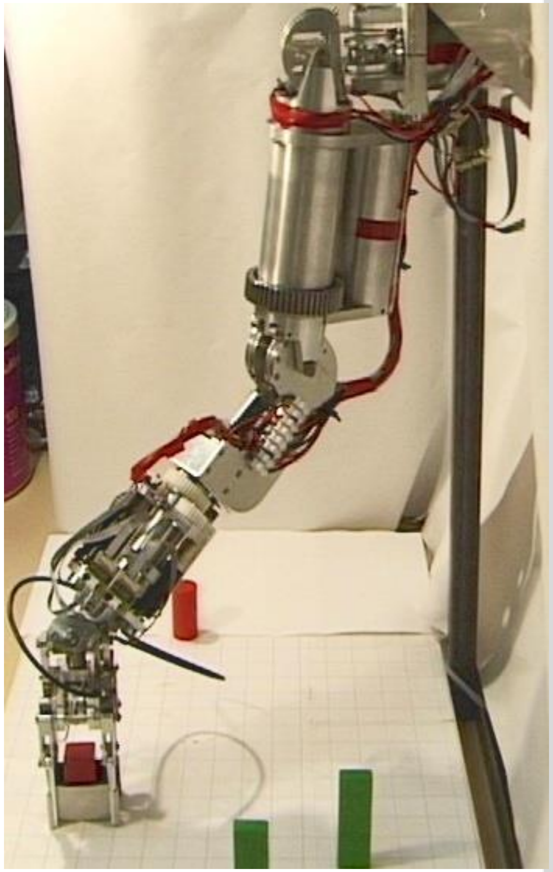


(Asfour 2003) „Sensomotorische Bewegungskoordination zur Handlungsausführung eines humanoiden Roboters“, Dissertation, Universität Karlsruhe

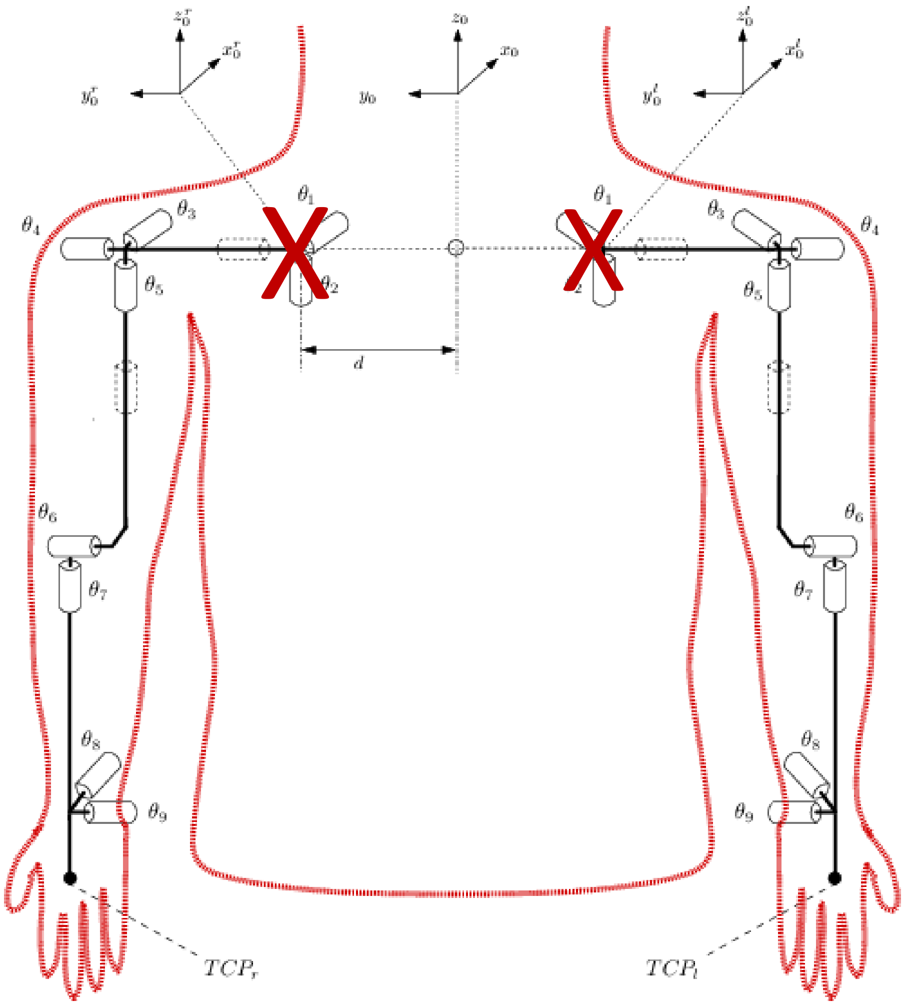
First Prototype: ARMAR-I arm



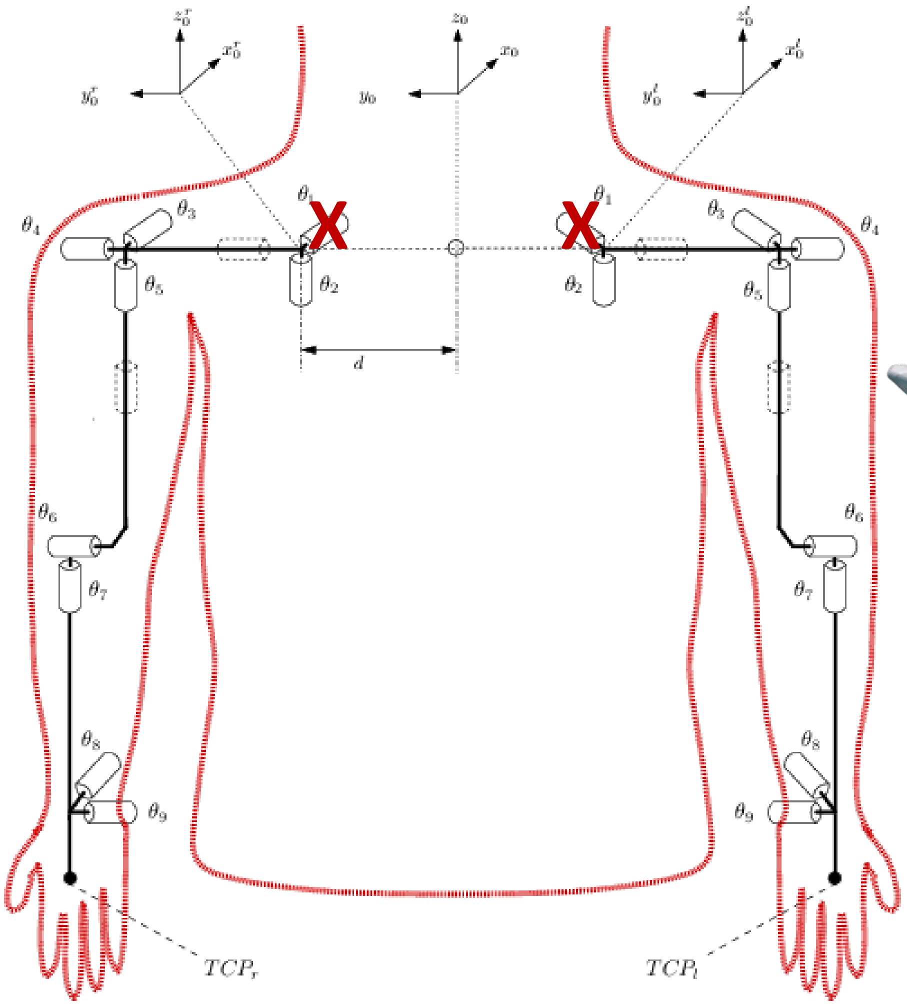
Joint		Motion Range
shoulder	θ_1	-45 ... 135
	θ_2	-90 ... 90
upperarm	θ_3	-160 ... 160
elbow	θ_4	0 ... 140
forearm	θ_5	-160 ... 160
wrist	θ_6	-45 ... 45
	θ_7	-45 ... 45

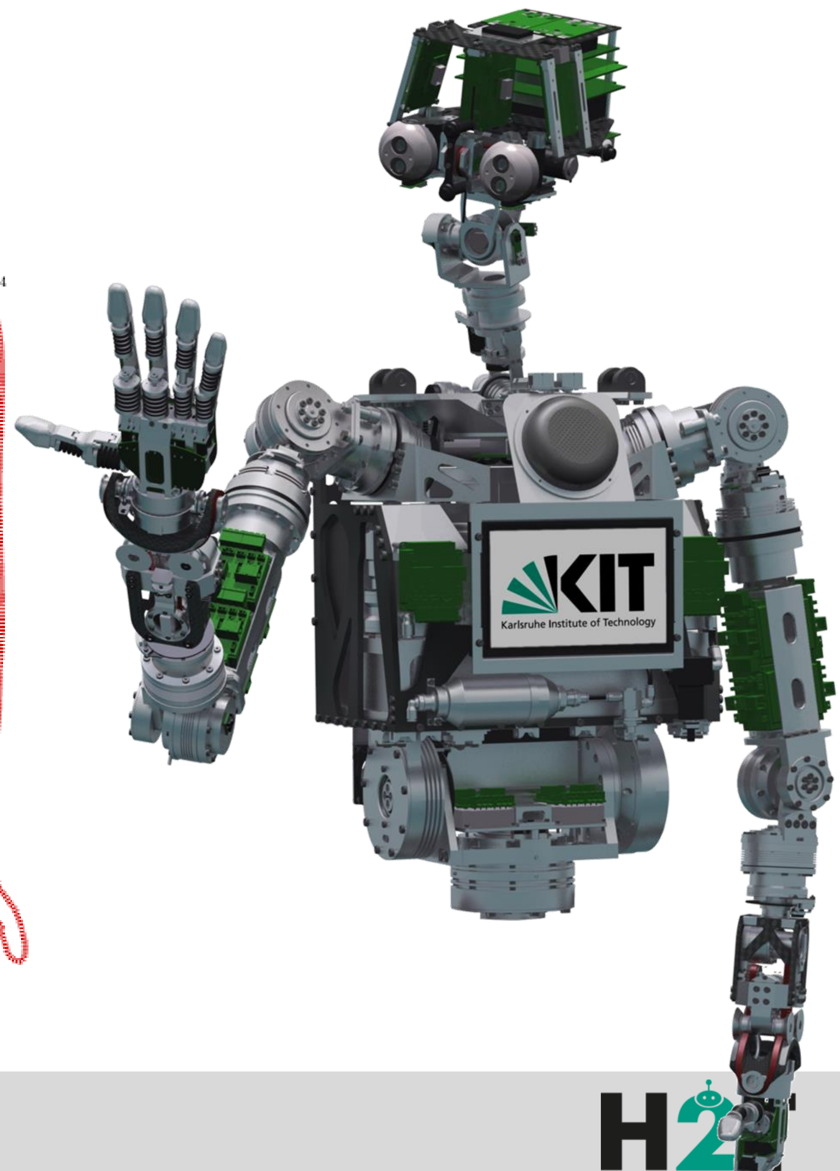


Kinematic model (ARMAR-III)

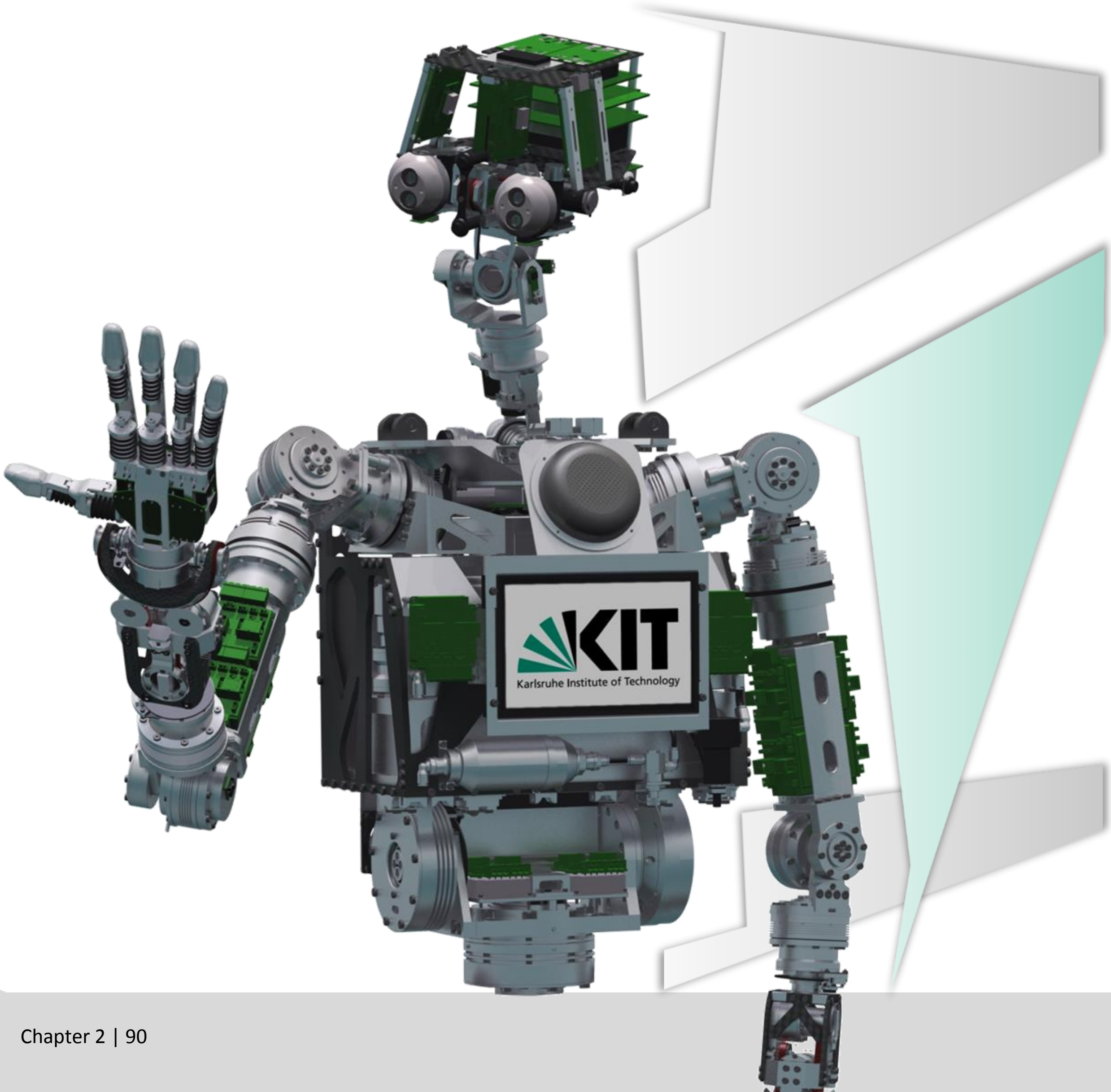


Kinematic model (ARMAR-IV)





ARMAR IV - Upper Body

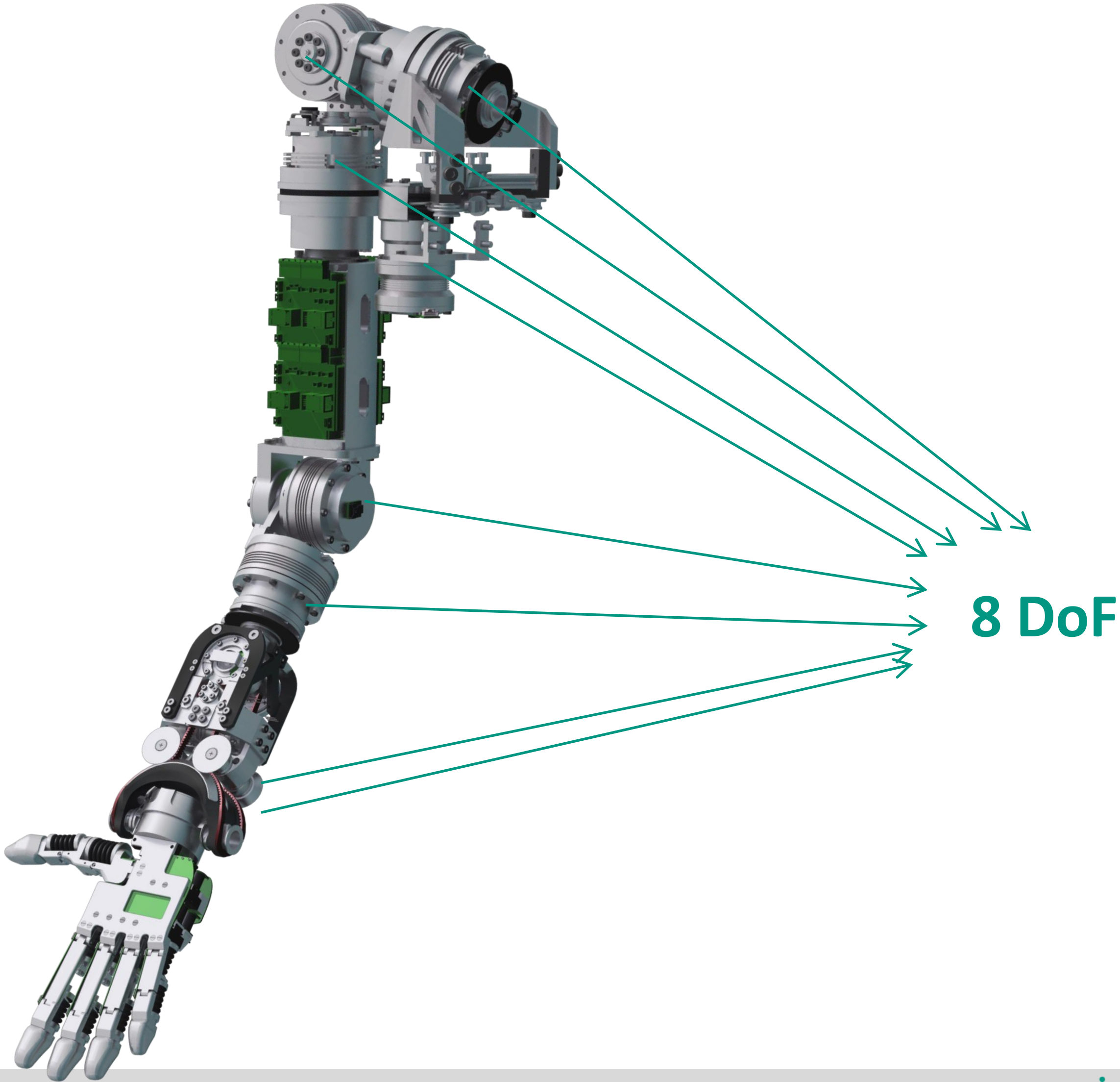


9 Degrees of Freedom

8 Degrees of Freedom

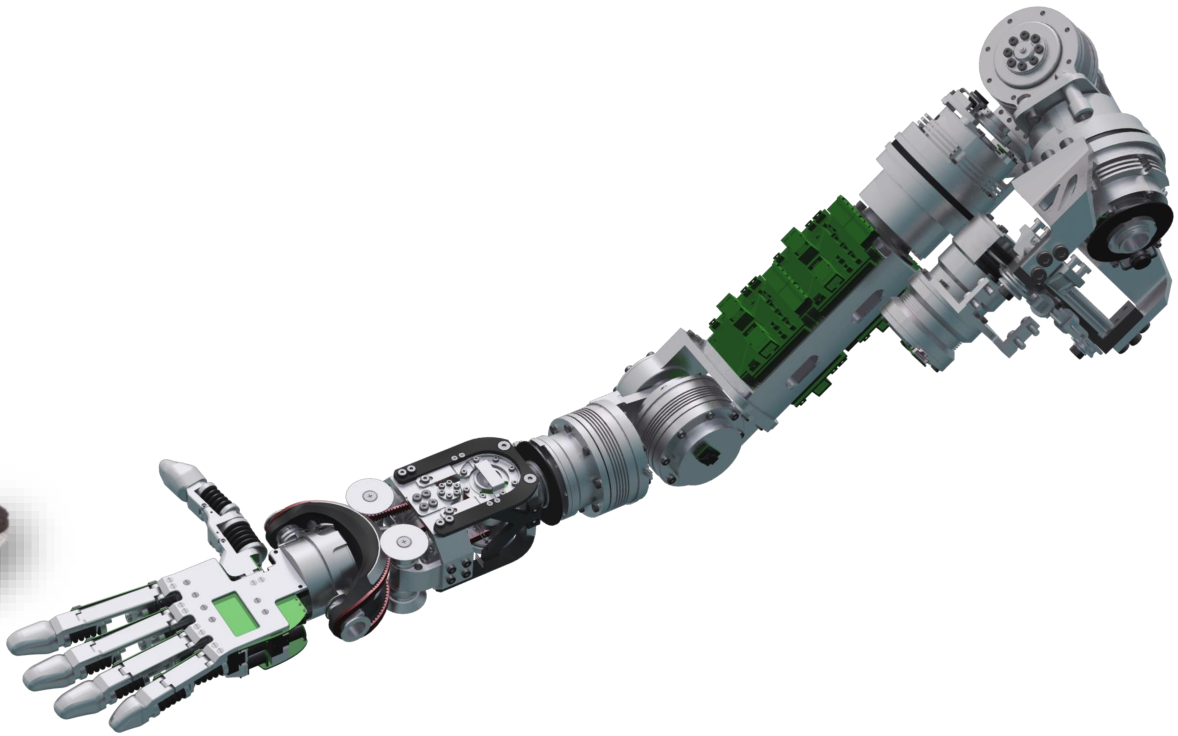
2 Degrees of Freedom

Arm in ARMAR-IV



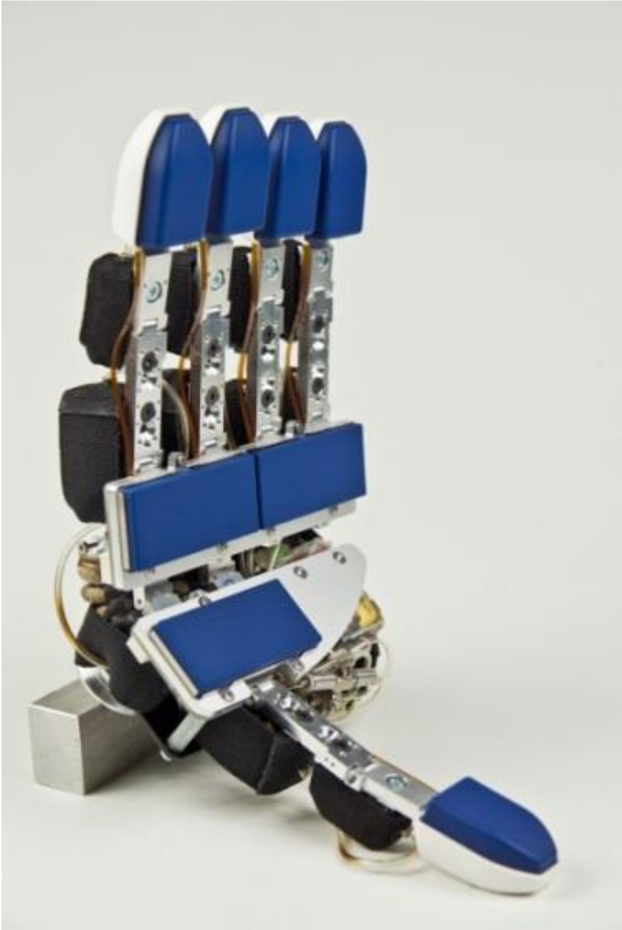
ARMAR-IV hand

- 11 DOF
- Anthropomorphic 5-finger hand
- Bi-directional pneumatic actuators
- Integrated valves, angel- and pressure-sensors and electronic



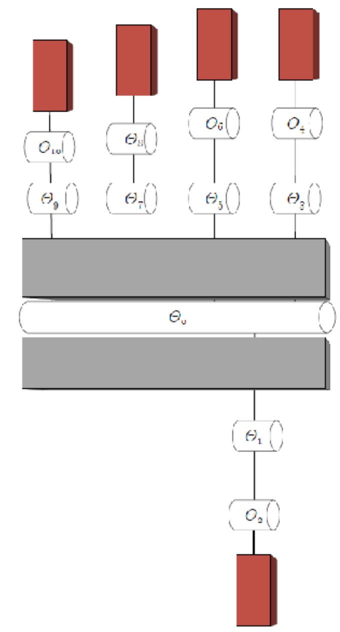
ARMAR-III hand (Version 2013)

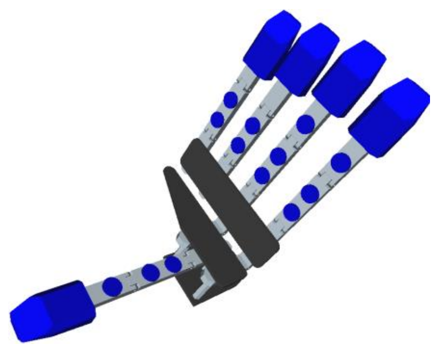
- New tactile sensor system
- 3 sensors in the palm
  - Tactile sensing matrix with 6x14 sensor cells
- Novel sensor for each fingertip
  - Tactile sensing matrix 4x8 sensor cells
  - Curved surface
- 12 bit sensor signal resolution
- Spatial resolution of 3.8 mm
  - Enhances tactile pressure profiles with a high spatial accuracy
- Integrated signal processor
- USB Interface



ARMAR-III hand

- **8 independent Degrees of Freedom**
  - 2 DoF per finger
    - For index, middle, thumb
  - 1 DoF in the palm
  - 1 DoF shared by pinkie and ring finger
- **Direct Kinematics**
- **Inverse Kinematics**
  - Virtual Model Control
  - Using a Physical simulation model (IPSA)
  - Compute velocity vectors from the difference between attractors and fingertip positions
  - Use simulated movements for the real hand
- Developed by Stefan Schulz und Georg Bretthauer



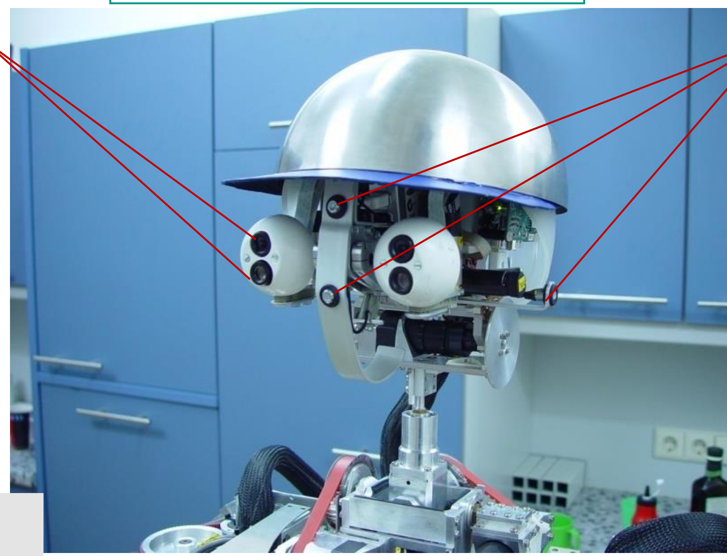


Karlsruhe Humanoid Head

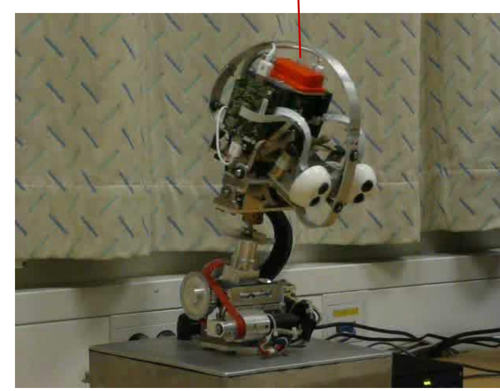
7 DOF
- 4 DOF neck
- 3 DOF eyes

Two cameras per eye
- wide-angle lens for peripheral vision
- narrow-angle lens for foveated vision

six microphones and six channel microphone pre-amplifier with integrated phantom power supply

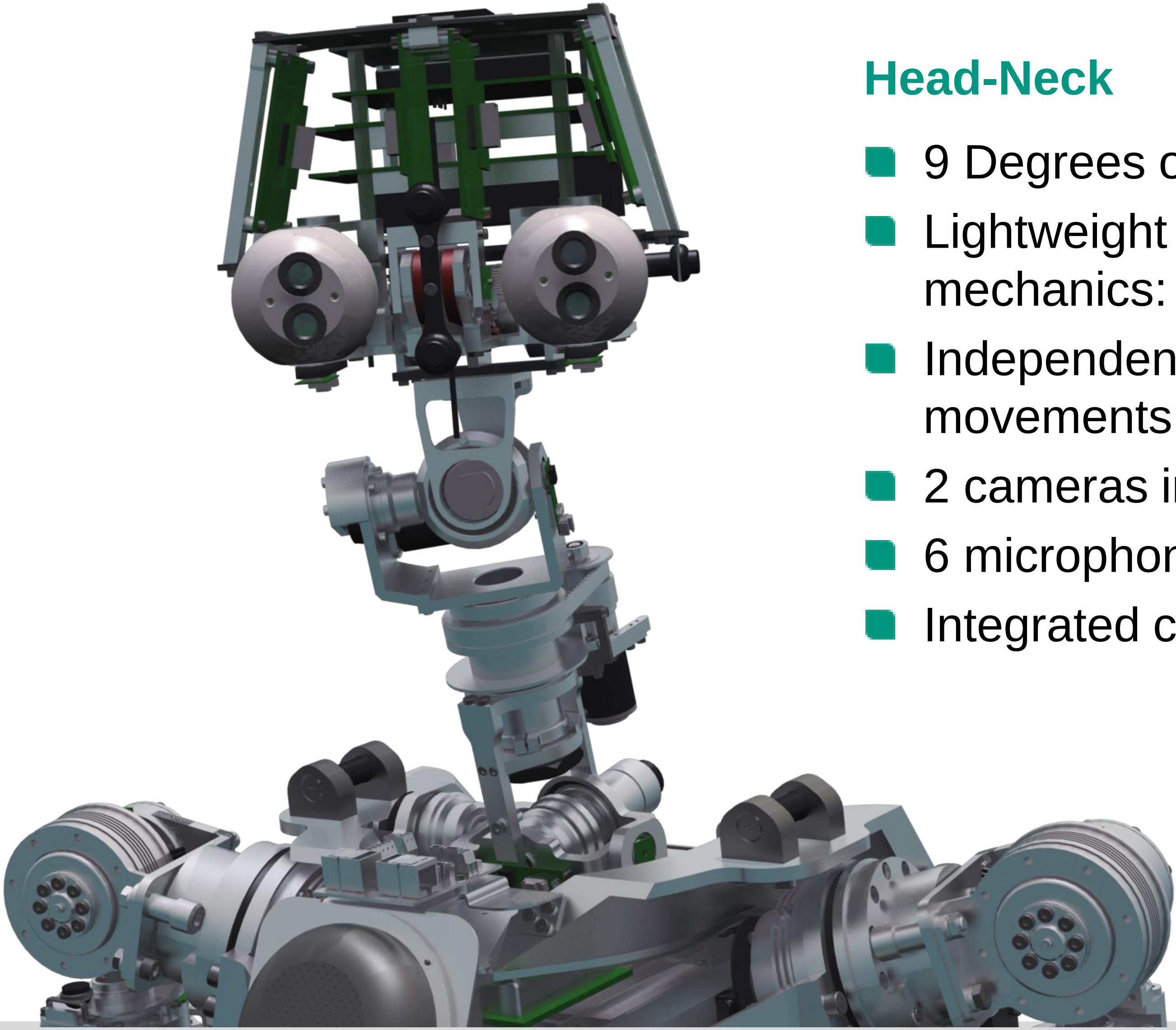


6D inertial sensor



Asfour, T. Welke, K. Azad, P. Ude, A. Dillmann, R. The Karlsruhe Humanoid Head. In Proc. Int. Conf. on Humanoid Robots, 2008

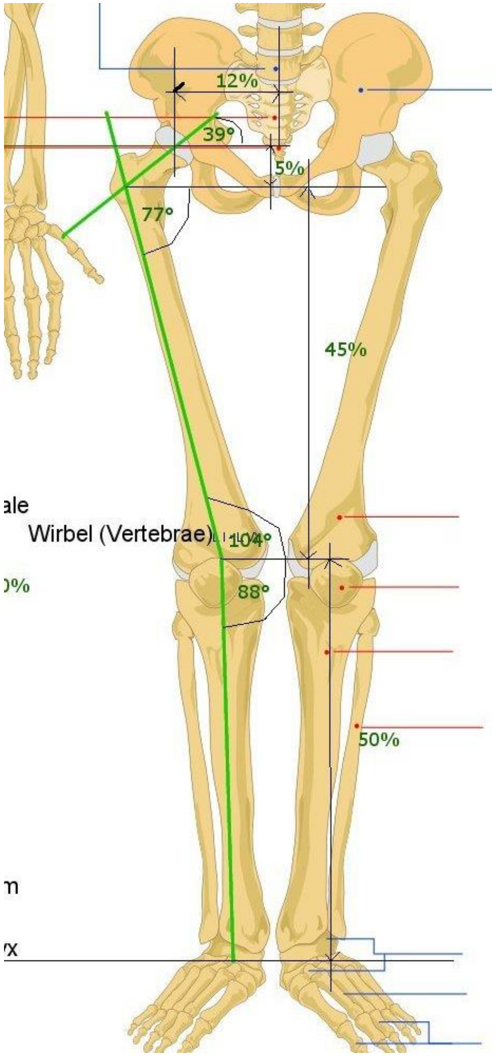
ARMAR IV - Head-Neck

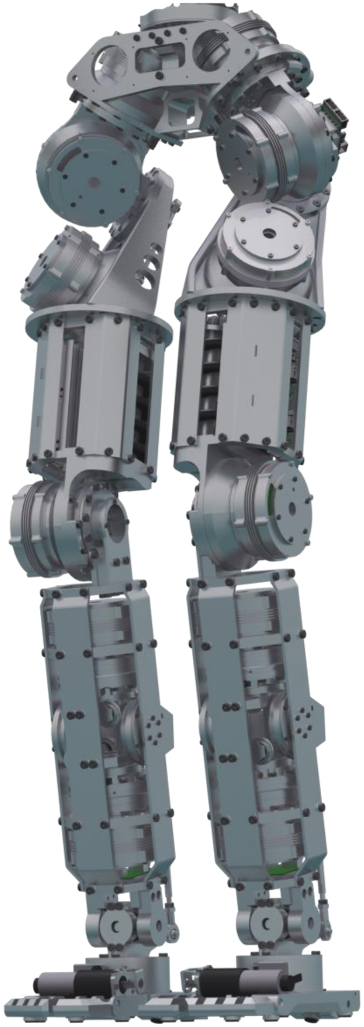


Head-Neck

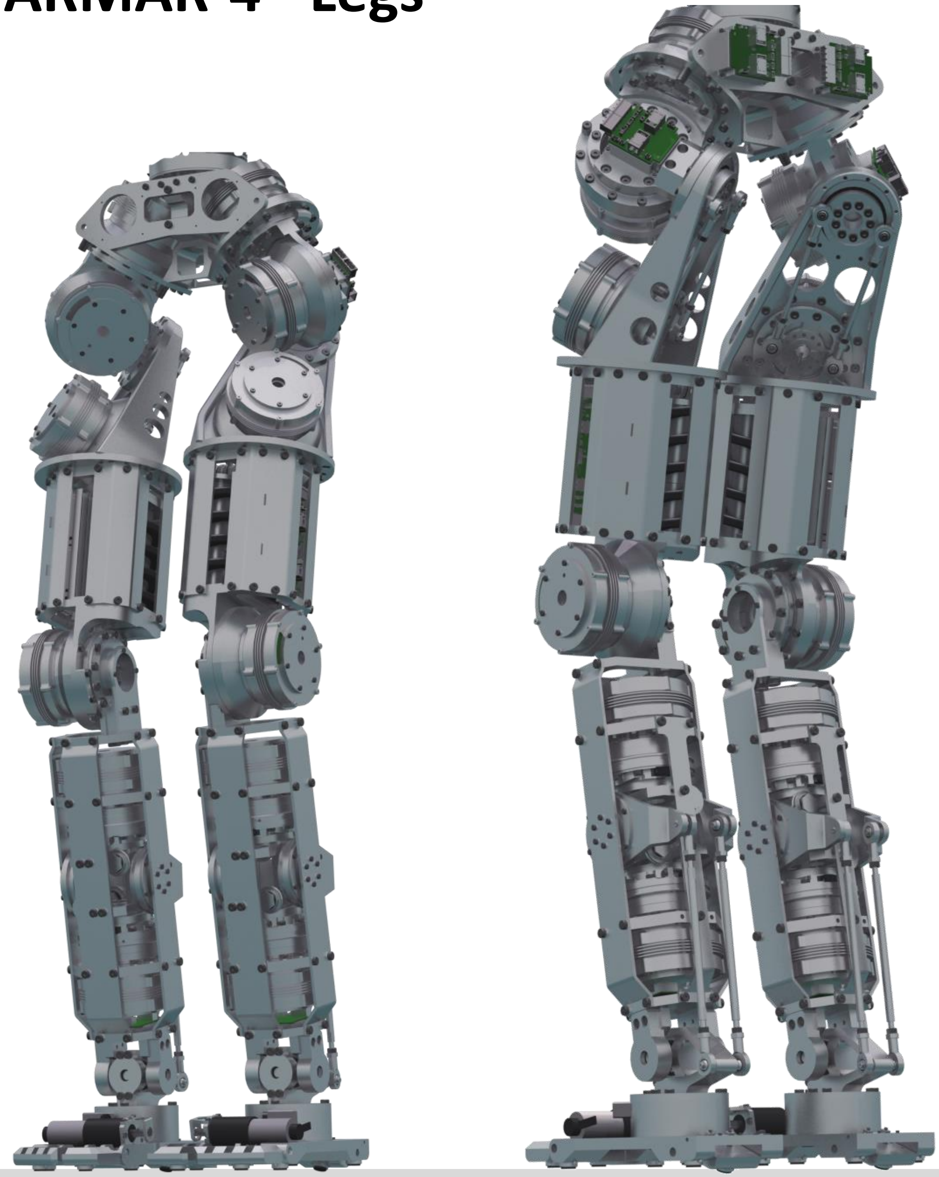
- 9 Degrees of freedom
- Lightweight design (weight of mechanics: 1412 g)
- Independent eye pan/tilt movements
- 2 cameras in each eyes
- 6 microphones
- Integrated computing power

Legs in ARMAR-IV





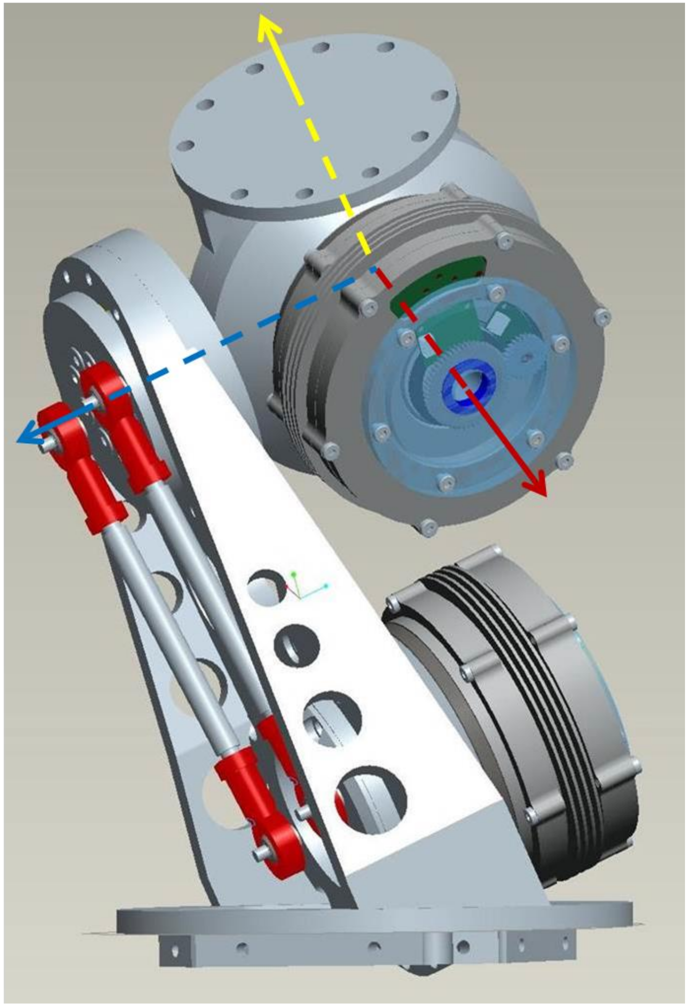
ARMAR-4 - Legs

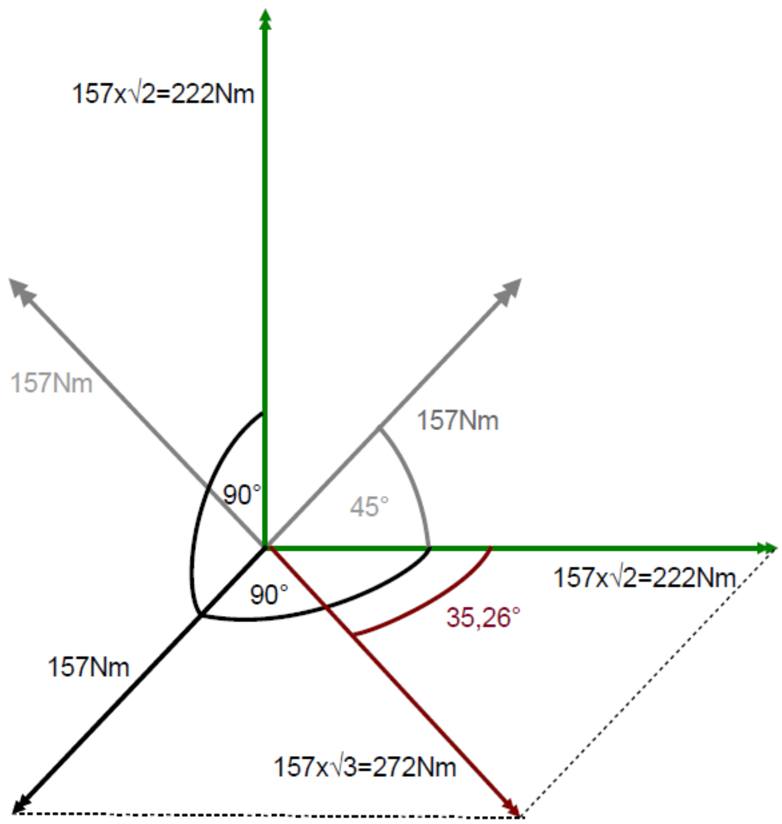


Legs

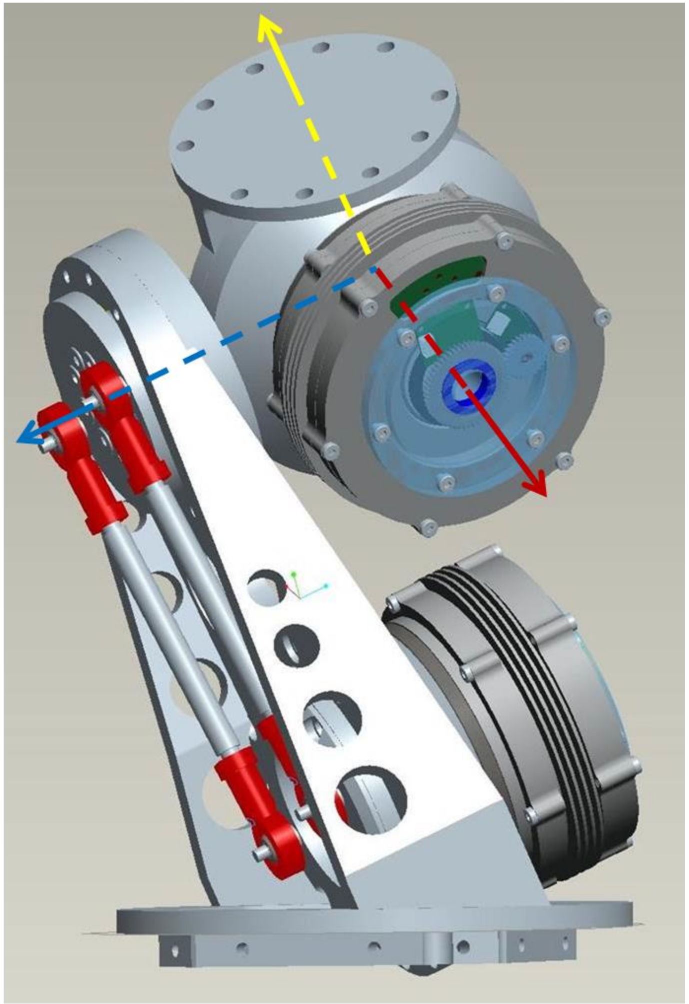
- 7 DOF
- Energy storage in the knees by use of two springs
- Differential kinematics in hip and ankle-joint
- Uniform driving units in all joints with only 11 mechanical parts → Cost-reduction
- Topology optimized hip
- Weight per driving unit: 1300 g

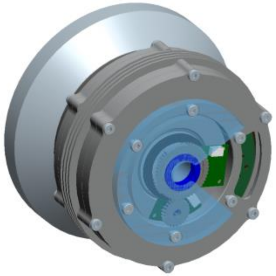
Hip kinematics

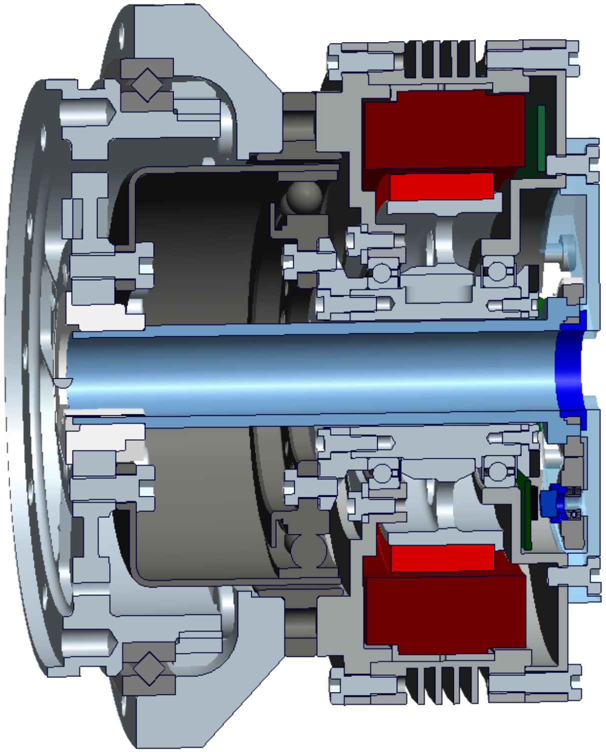




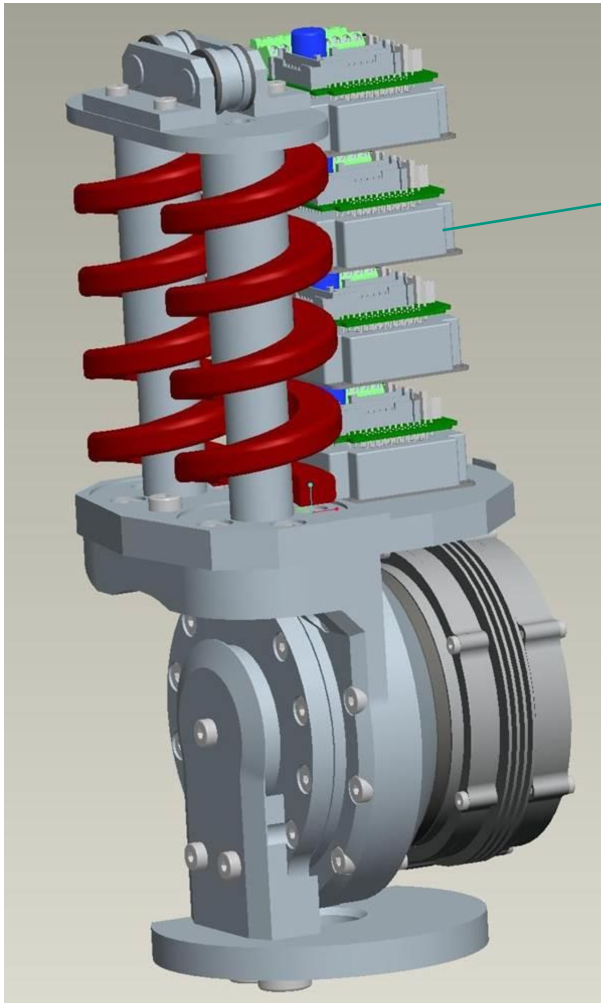
Hip, leg

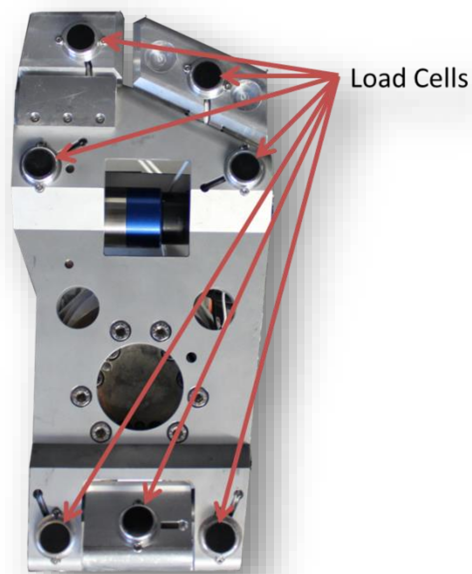






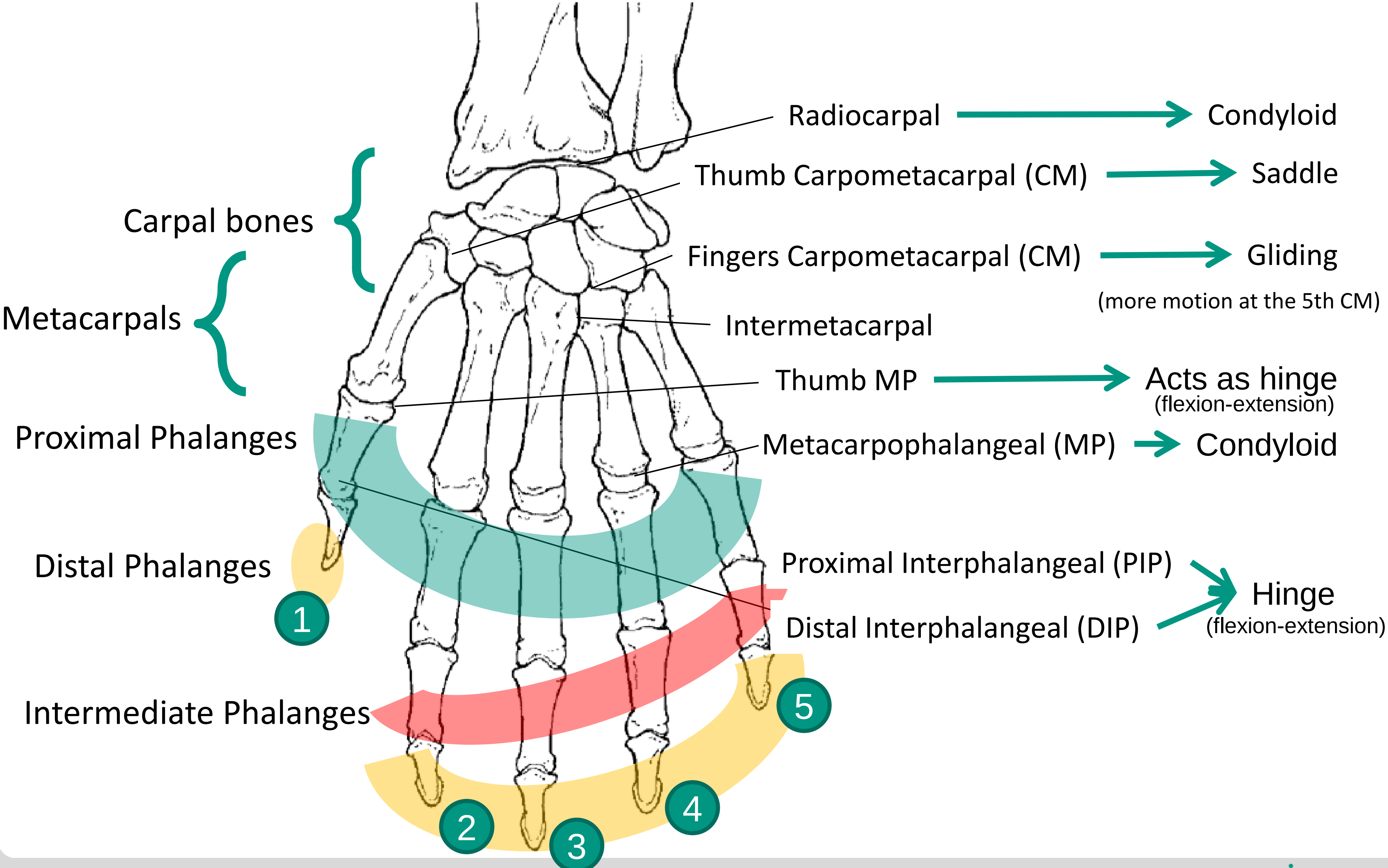
Knee, lower leg





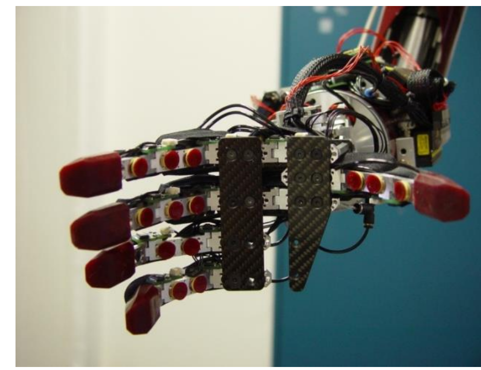
Human and humanoid hands

Hand : Bones and joints



Karlsruhe 5-Finger Hand

- Five finger hand
- Carbon and aluminium structure
- Fluid actuators
  - Located directly at the joints
  - Pneumatically actuated
- Joint sensors
  - Located directly at the joints
  - Absolute joint angles
- Force position control
  - For arbitrary joint configurations
  - Not limited to a predefined set of hand preshapes

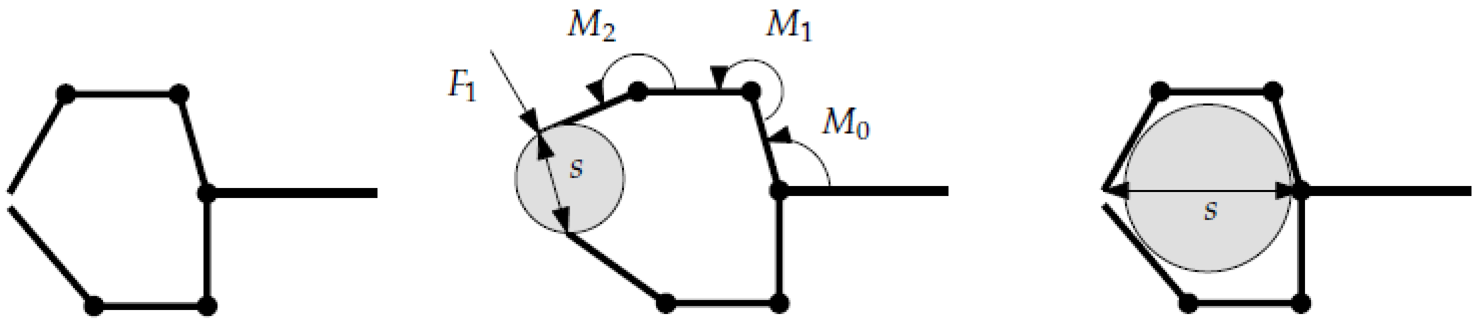


- Developed by Dr. Stefan Schulz and Prof. Georg Bretthauer

Contact detection and grasp verification

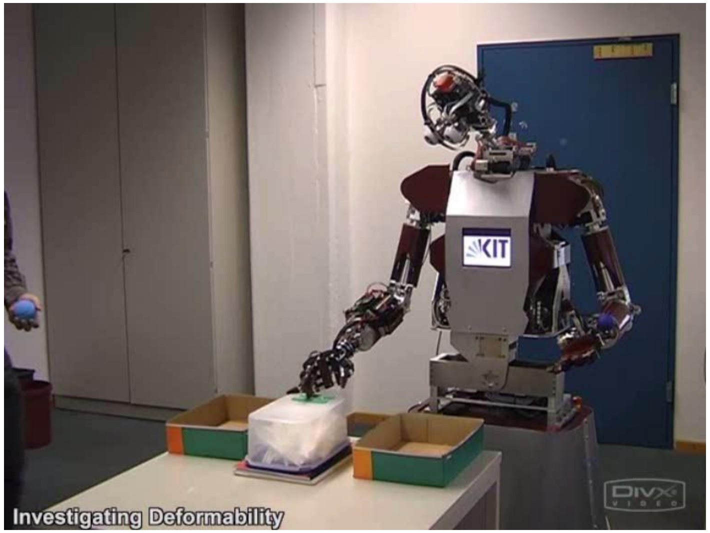
- **Contact Detection using joint torques**
  - Compute weighted sum of finger joint torques
  - Contact is detected when a threshold is surpassed

- **Object grasped successfully?**
  - Calculate distances:
    - between different fingertips (for precision grasps)
    - between fingertips and the palm (for power grasps)



Detection of Deformability

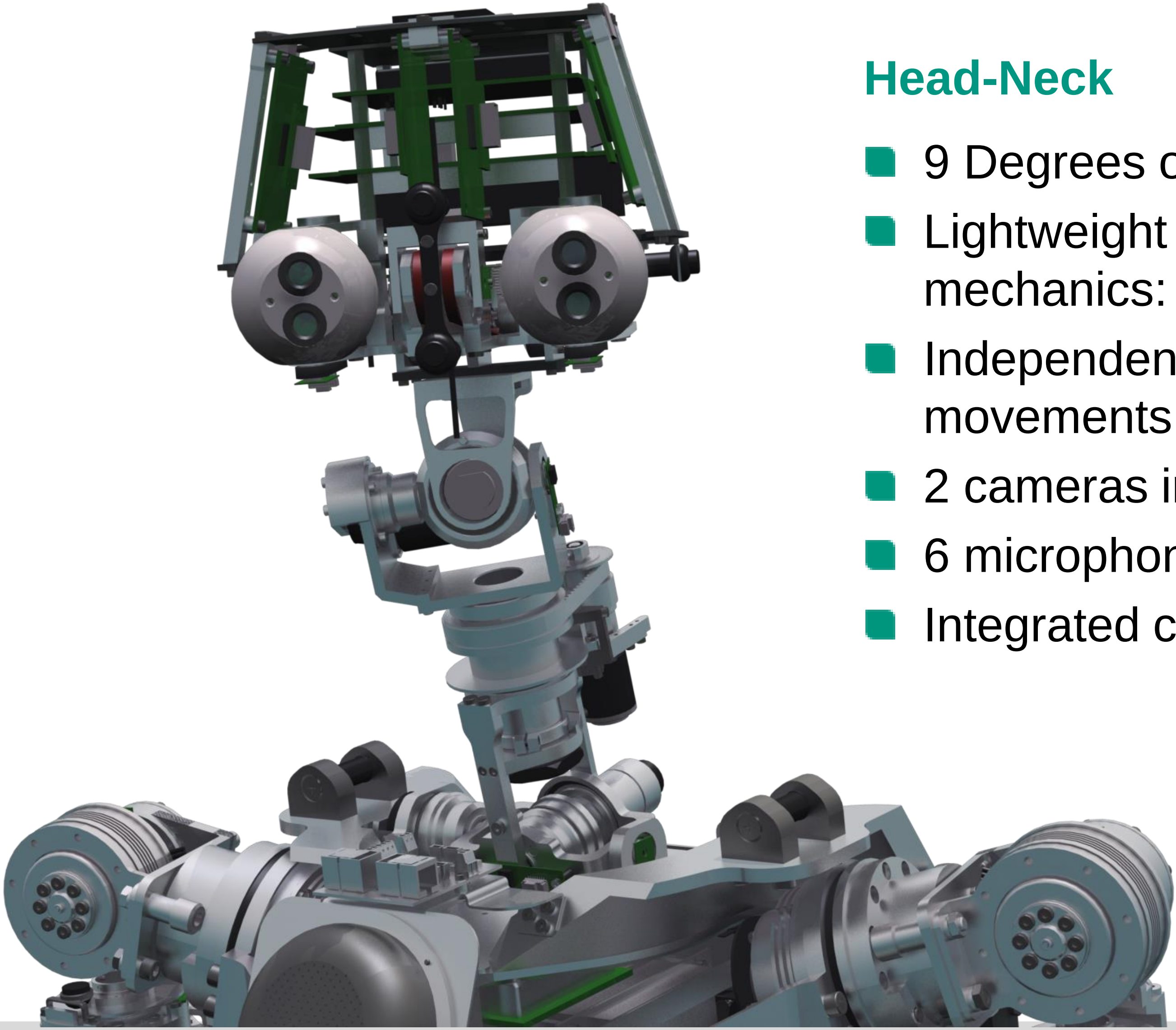
- **Deformable Objects can be detected:**
  - Grasp an object
  - Verify that the grasp was successful
  - Increase the joint torques
  - Determine distances between the fingertips
    - Decreased distances indicate a deformable object



Verification of object deformability

A. Bierbaum, J. Schill, T. Asfour and R. Dillmann
Force Position Control for a Pneumatic Anthropomorphic Hand. In Proc. Int. Conf. on Humanoid Robots, Paris, France, 2009

ARMAR IV - Head-Neck



Head-Neck

- 9 Degrees of freedom
- Lightweight design (weight of mechanics: 1412 g)
- Independent eye pan/tilt movements
- 2 cameras in each eyes
- 6 microphones
- Integrated computing power

ARMAR IV - Arm / Hand

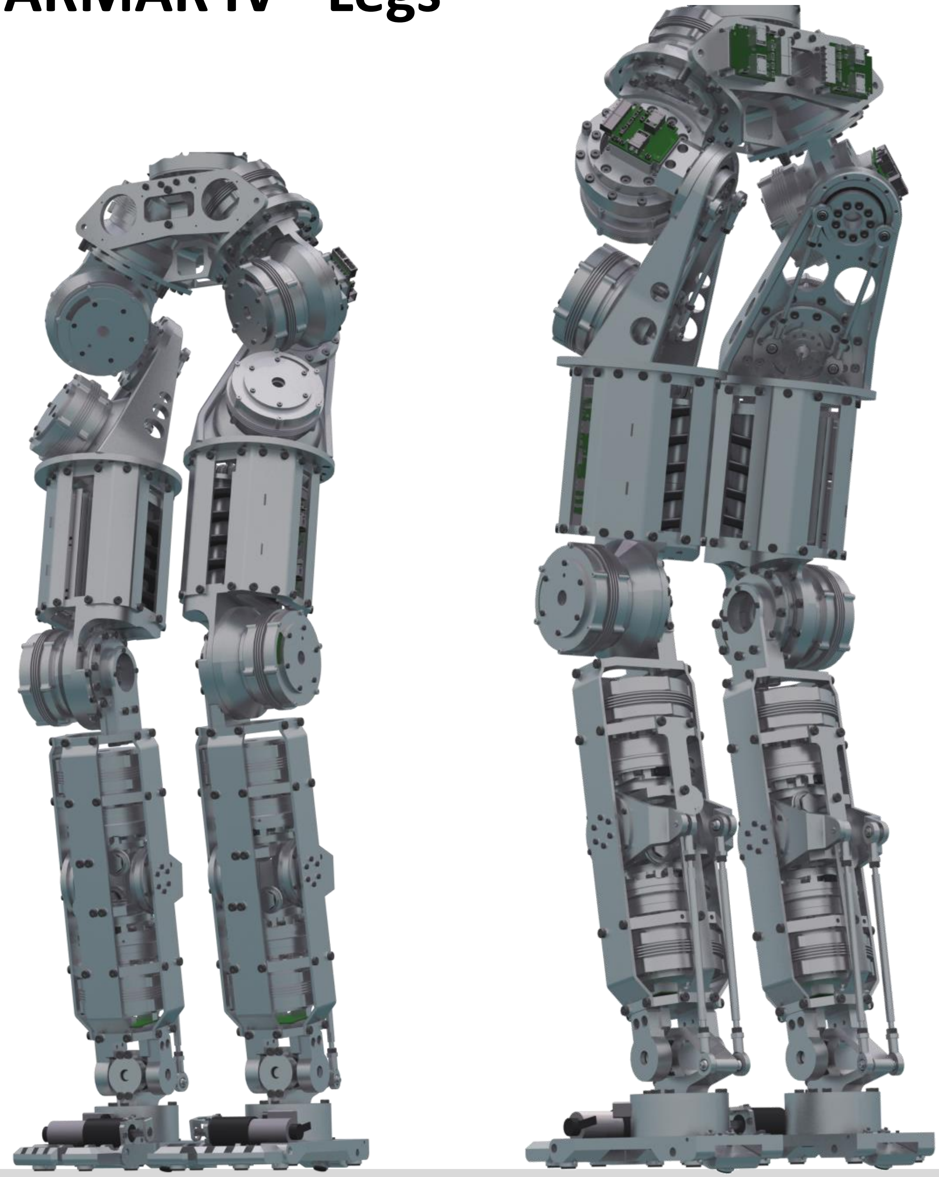
Arm

- 8 DOF
- New shoulder and wrist-design with virtual axis
- Lightweight material design (Aluminium, Magnesium and carbon fiber reinforced polymers)
- Integrated torque measurement in each DoF

Hand

- 11 DOF
- Anthropomorphic 5-finger hand
- Bi-directional pneumatic actuators
- Integrated valves, angel- and pressure-sensors and electronic

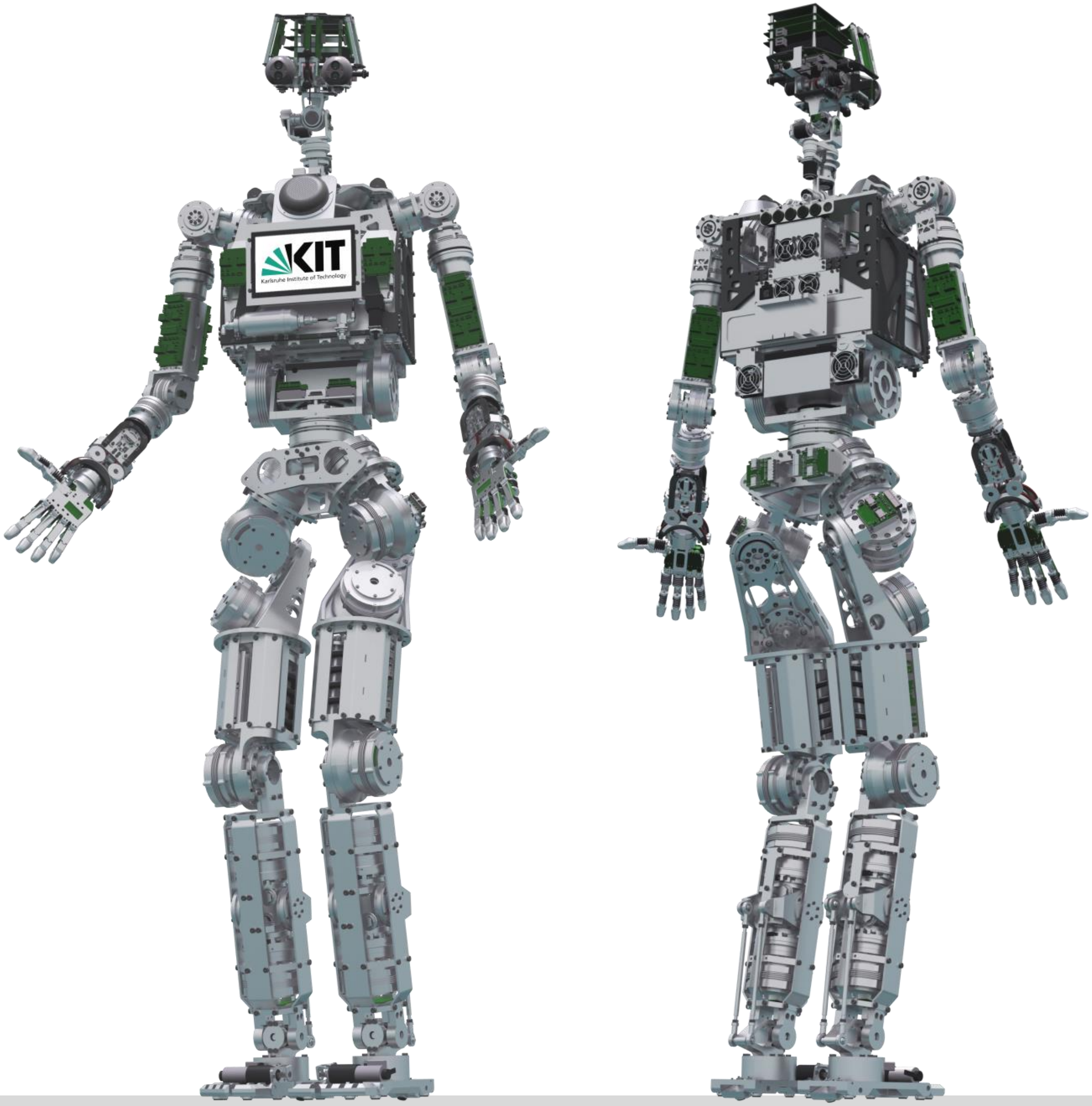
ARMAR IV - Legs



Legs

- 7 DOF
- Topology optimized hip
- Energy storage in the knees by use of two springs
- Differential kinematics in hip and ankle-joint
- Uniform driving units in all joints with only 11 mechanical parts → Cost-reduction
- Weight per driving unit: 1300 g

ARMAR-IV



- 63 DOF
- 170 cm
- 70 kg

ARMAR-4: Mechano-Informatics

- Torque controlled
- 3 on-board embedded PCs
- 76 Microcontroller
- 6 CAN Buses

- 63 DOF
  - 41 electrically-driven
  - 22 pneumatically-driven (Hand)

- 214 Sensors
  - 4 Cameras
  - 6 Microphones
  - 4 6D-force-torque sensors
  - 2 IMUs
  - 128 position (incremental and absolute), torque and temperature sensors in arm, leg and hip joints
  - 18 position (incremental and absolute) sensors in head joints
  - 14 load cells in the feet
  - 22 encoders in hand joints
  - 20 pressure sensors in hand actuators
  - …

More than mechatronics

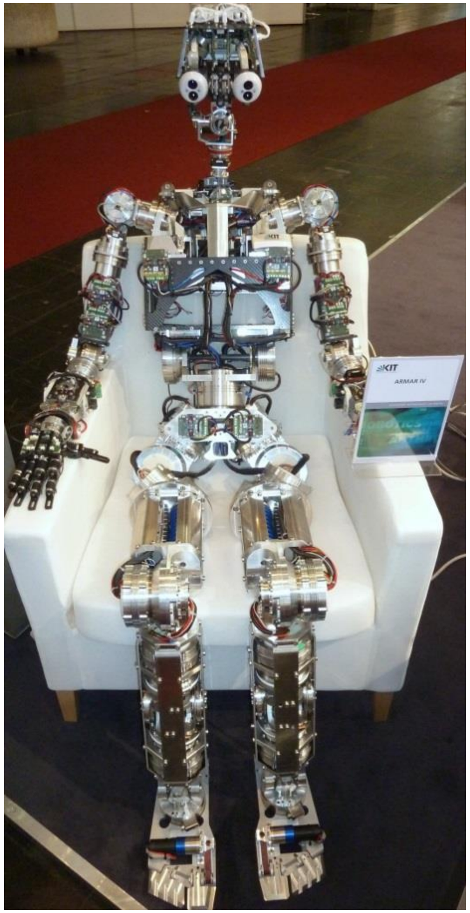
ARMAR-IV

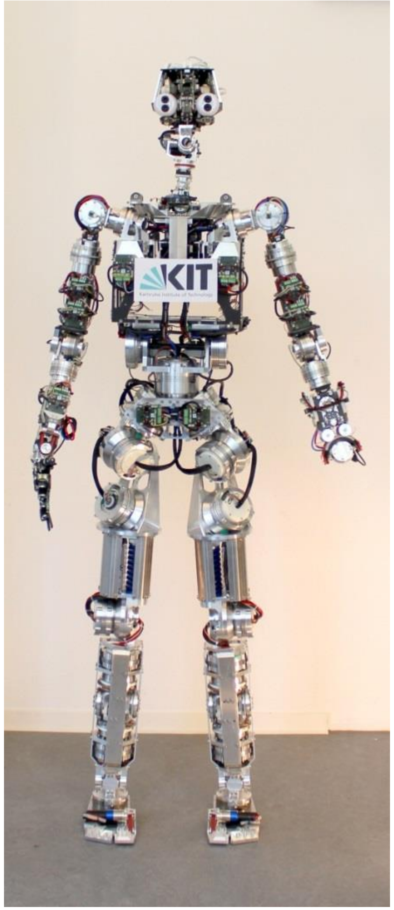
made@KIT

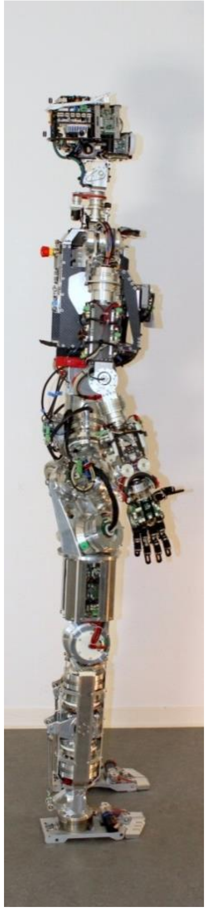
70 kg

170 cm

ARMAR-IV

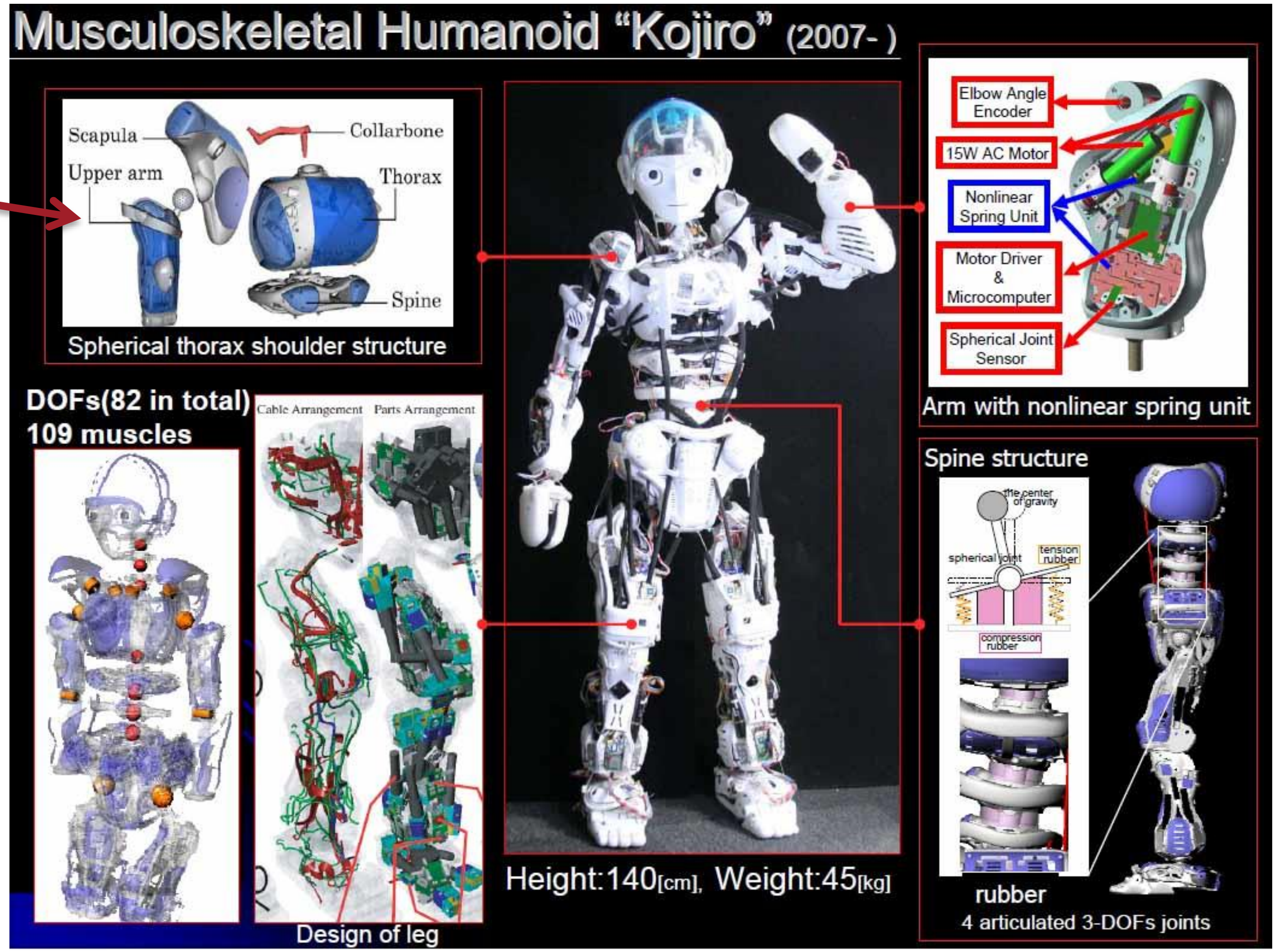






T. Asfour, J. Schill, H. Peters, C. Klas, J. Bücker, C. Sander, S. Schulz, A. Kargov, T. Werner and V. Bartenbach, **ARMAR-4: A 63 DOF Torque Controlled Humanoid Robot**, IEEE/RAS International Conference on Humanoid Robots (Humanoids), October, 2013

Shoulder-arm in Kojiro



http://www.jsk.t.u-tokyo.ac.jp/research/kojiro.html