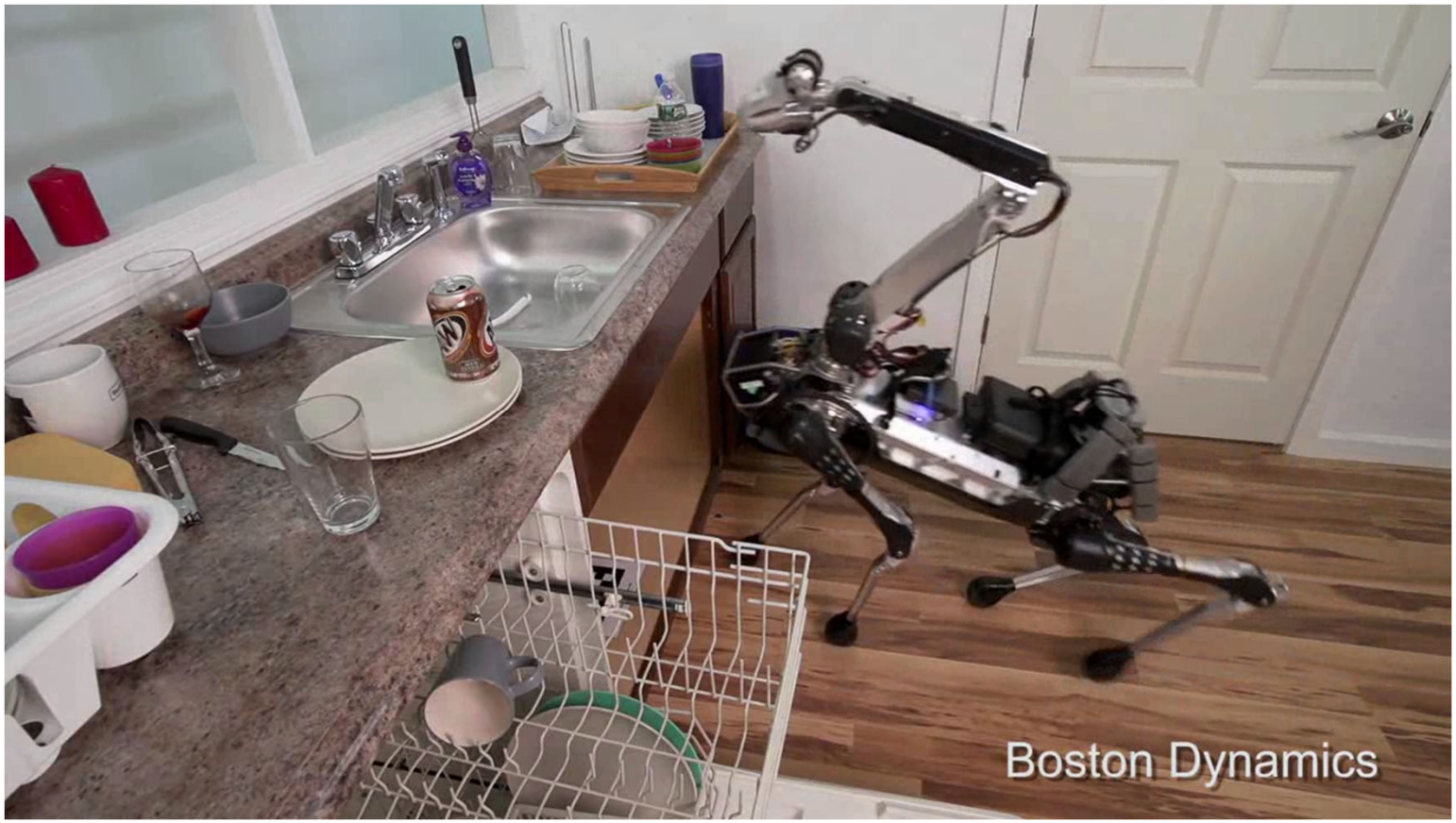
Master in
Computational Science and Engineering
Specialization in Robotics

ETH Zurich, D-MAVT, D-INFK, D-ITET, D-HEST

https://ethz.ch/content/dam/ethz/special-interest/study-programme-websites/ms-compsci-and-eng-dam/documents/master-programme/MSc-CSE-GL-curr.pdf

Robotics tomorrow | Service Robots outside the production halls



SpotMini | electic quadruped, Boston Dynamics

https://www.youtube.com/watch?v=tf7IEVTDjng

Service Robots | Key Challenges

Our real "physical" world is ***multimodal***, very ***diverse*** and ***complex***.

We need robots that …

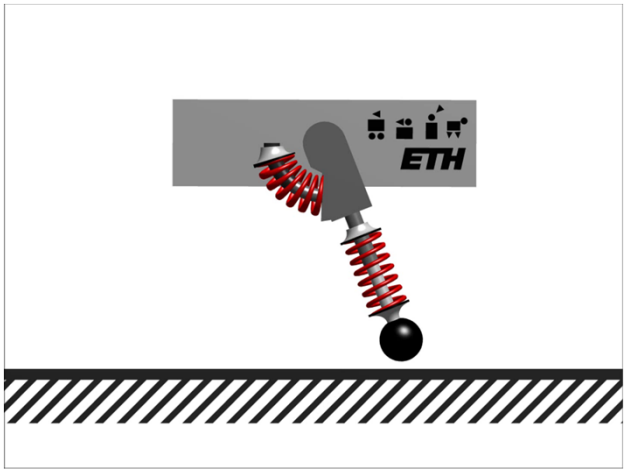
- … can *dealing* with ***uncertain*** and ***partially available information***
- … ***see***, ***feel*** and ***understand*** their environment
- … have ***torque*** and ***force*** control for tactile interaction ("soft robots")
- … offer ***intuitive human-machine interfaces***
- … ***learn*** and ***adapt*** every day

→ **all this requires AI/ML for intelligent control, but also novel sensing, actuation and robot concepts!!**

50x speed
https://www.youtube.com/watch?v=gy5g33S0Gzo

Willow Garage

Walking Robot ANYmal | *designed for challenging environments*

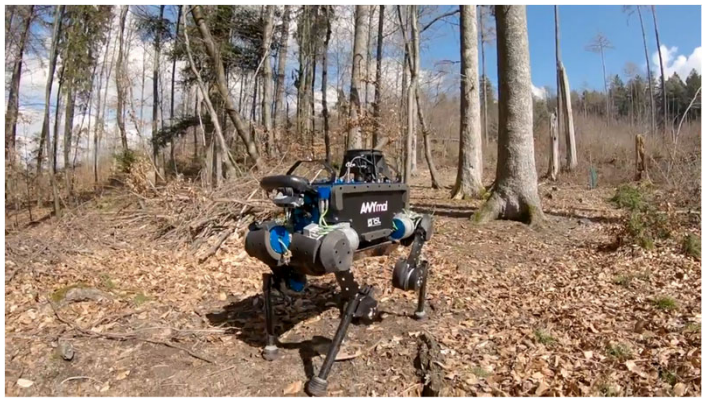


RSL Robotic Systems Lab

Prof. Marco Hutter

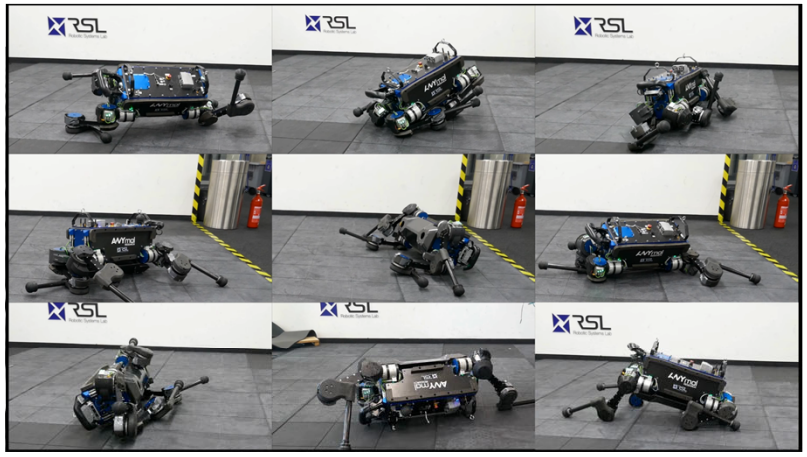
ANYmal – "soft" interaction with the environment | the ultimate quadruped

https://www.youtube.com/watch?v=EI1zBTYpXW0



Reinforcement Learning | robot learning to walk

- Goal: given the actual state, learn the best action (leg movements) to *achieve the optimal next state.*



Robotic Systems Lab
Prof. Marco Hutter

Service Drones | flying robots for challenging tasks

wingtra – most elegant VTOL

Spinoff ETH zürich

| from student project to startup

https://www.youtube.com/watch?v=QADvPDWtgFU

Atlantik Solar solar airplane

| 81 hours non-stop in summer 2015

| 5.64 m, 6.2 kg

https://www.youtube.com/watch?v=8m4_NpTQn0E

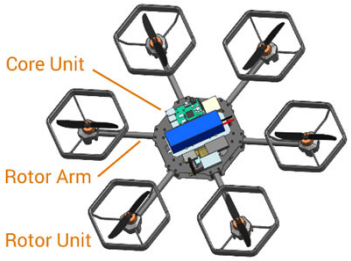
https://www.youtube.com/watch?v=wyS6W1t_ryQ

Voliro – future of flying robots

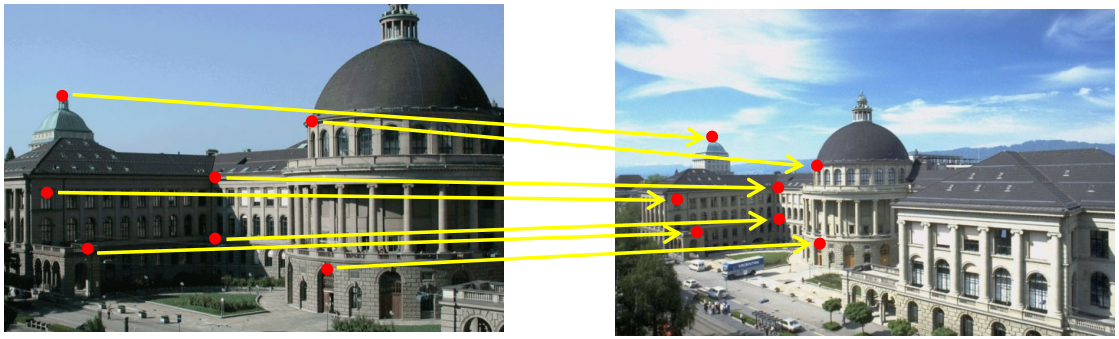
Spinoff ETH zürich

| the omni-directional multi-copter

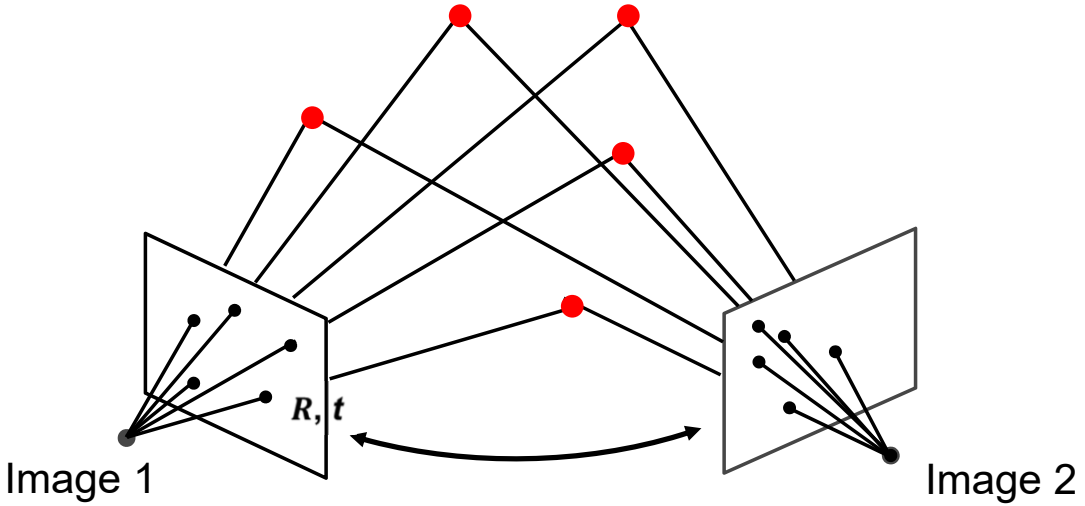
https://www.youtube.com/watch?v=9FJn_t-YCwM



"Seeing" | Visual-Inertial Motion Estimation

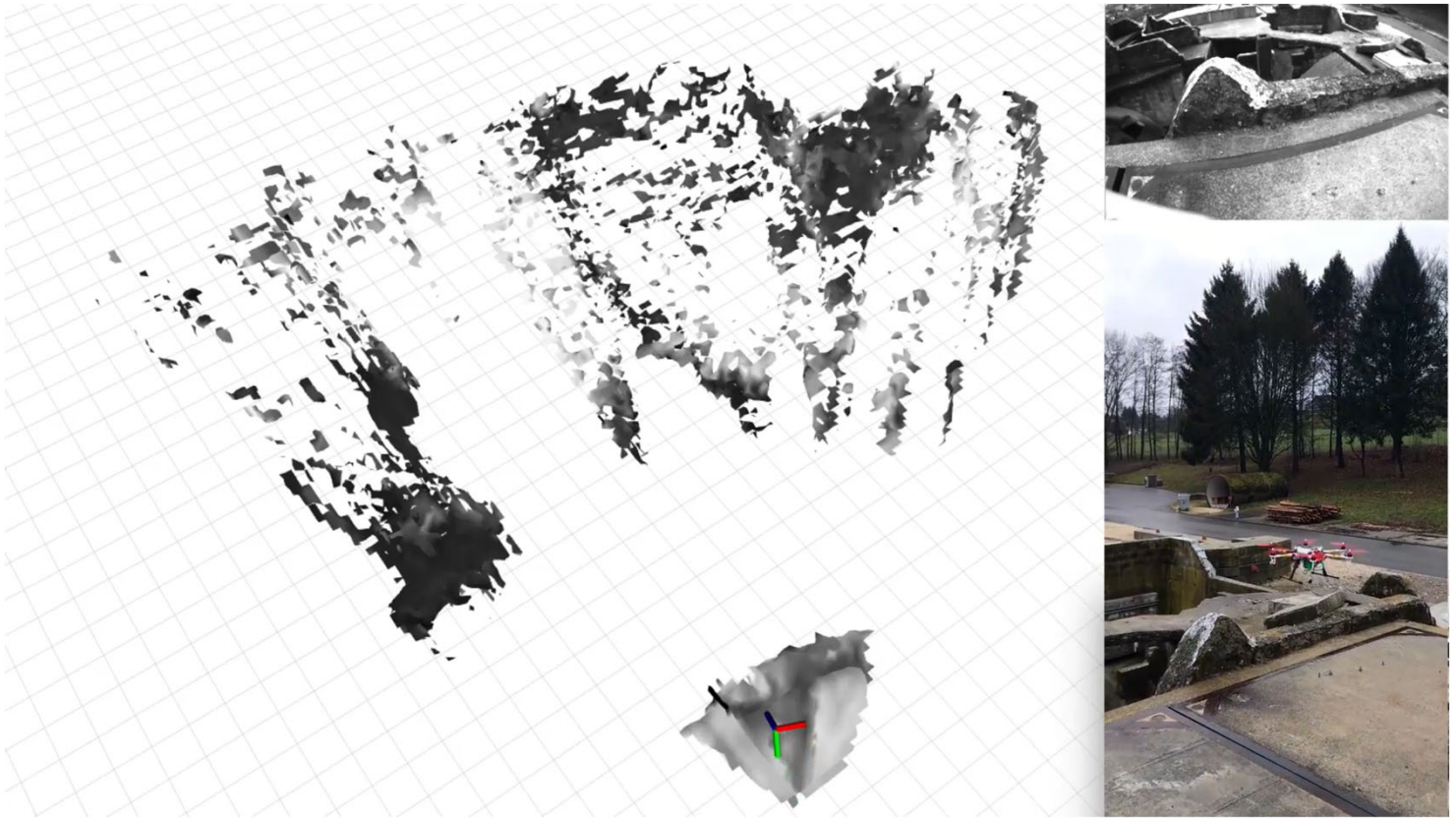


Google Project Tango



https://www.youtube.com/watch?v=yvgPrZNp4So

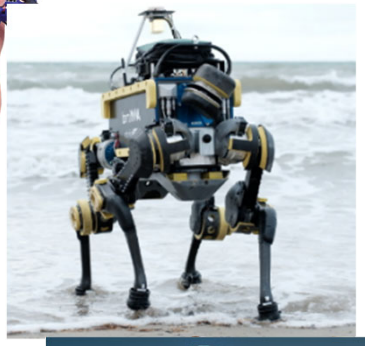
3D Reconstruction | on-board a drone

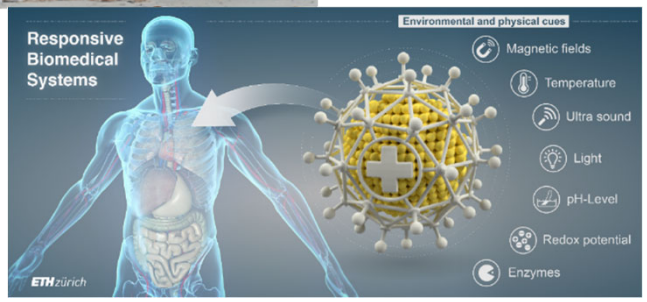


https://www.youtube.com/watch?v=49WiPHkkhBw

Interdisciplinary, exciting and highly demanded in industry

- **Key Topics**
  - **Systems Engineering**
    - Design and Optimization of Products and Systems
  - **Physical Modelling and Simulation**
  - **Optimization and Control**
  - **Perception, Graphics, Virtual Reality**
  - **Embedded and Distributed Computing**
  - **Artificial Intelligence & Machine Learning**
  - **Robotics**
    - Design, Modelling, Control and Intelligence
  - **Challenging Applications**
    - autonomous vehicles and transportation, VR/AR, search and rescue, smart agriculture and construction, energy technology, biomedical and much more.





Field of Specialization "**Robotics Courses**" (*Contact:* Roland Siegwart, D-MAVT)

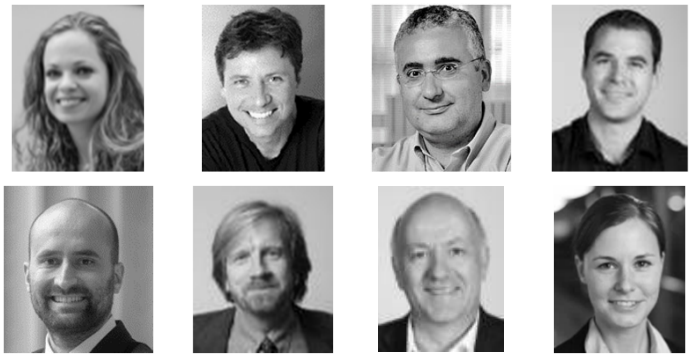
Course*	SWS	Sem.	Dep.	KP
Theory of Robotics and Mechatronics	3G	HS	MAVT	4
Autonomous Mobile Robots	4G	FS	MAVT	5
Probabilistic Artificial Intelligence	2V 1U 1A	HS	INFK	5
Deep Learning	2V 1U	HS	INFK	4
Computer Vision	3V 1U 1A	HS	INFK	6
Image Analysis and Computer Vision	3V 1U	HS	ITET	6
Dynamic Programming and Optimal Control	2V 1U	HS	MAVT	4
Recursive Estimation	2V 1U	HS	MAVT	4
Robot Dynamics	2V 1U	HS	MAVT	4
Machine Learning	3V 2U 2A	HS	INFK	8
3D Vision	3G	FS	INFK	4
Seminar in Robotics for CSE		HS / FS	RW	4

* **five courses** from the fields of specialization, including the seminar

Core Faculty in Robotics (for Projects and Seminars)

D-MAVT

- Margarita Chli
- Raffaello D'Andrea
- Emilio Frazzoli
- Marco Hutter
- Robert Katzschmann
- Brad Nelson
- Roland Siegwart
- Melanie Zeilinger



D-INFK

- Stelian Coros
- Otmar Hilliges
- Marc Pollefeys
- Siyu Tang

D-ITET

- Roy Smith
- Luc van Gool

D-HEST

- Roger Gassert
- Robert Riener
- Simone Schürle

Recommended Lecture Series by International Experts

- **Distinguished Seminars in Robotics, Systems and Controls**
  - http://www.msrl.ethz.ch/education/Distinguished_Seminar_RSC.html
- **ETHZ Control Seminars**
  - http://control.ee.ethz.ch/
- **ETHZ Computer Science Colloquium**
  - http://www.inf.ethz.ch/news/colloquium/

Research Overview of Core Faculty in Robotics

D-MAVT

D-INFK

D-ITET

D-HEST

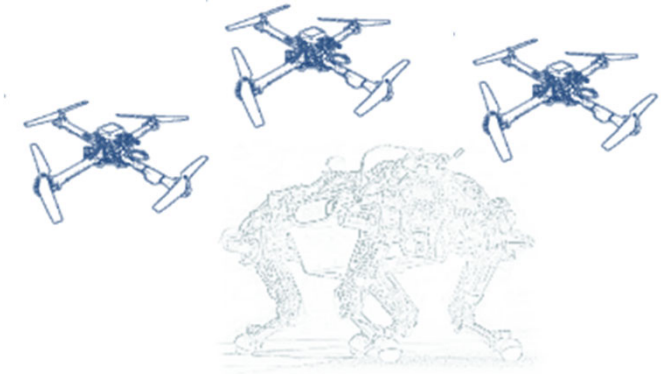
Prof. Dr. Margarita Chli

- **Affiliation:**
  - D-MAVT
    - Vision for Robotics Lab
- **Research Areas**

  Vision-based perception for robots
  – focus on small UAVs
  - Robot Navigation
  - Scene Reconstruction / Understanding
  - Collaborative Robot sensing & mapping

V4RL VISION FOR ROBOTICS LAB

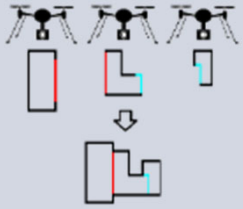
www.v4rl.ethz.ch



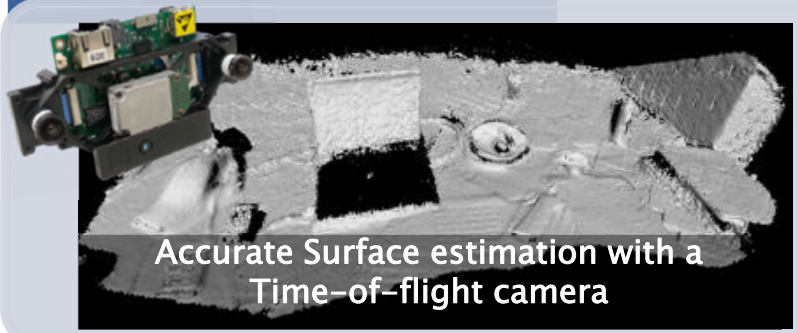
Examples of Research Projects

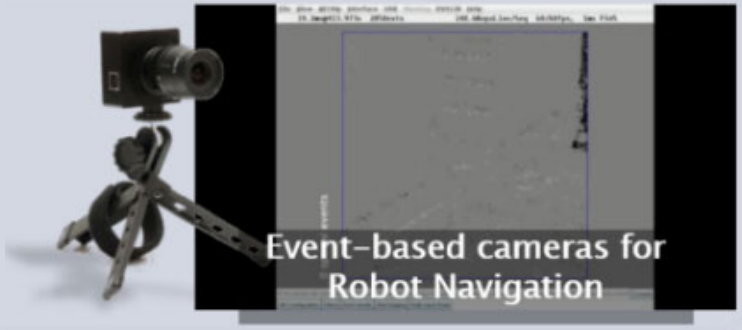
V4RL VISION FOR ROBOTICS LAB

MONOCULAR CAMERA



OTHER VISION-BASED SENSORS





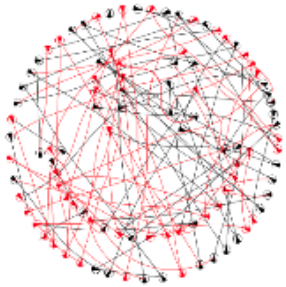
Prof. Dr. Raffaello D'Andrea

- **Affiliation:**
  - D-MAVT
    - Institute for Dynamic Systems and Control
- **Research Areas**
  - Design and control of distributed, autonomous systems
  - Design and control of systems capable of complex motion
  - For example:
    - Systems with many interconnected components
    - Systems that learn from experience and improve their performance over time
    - Autonomous vehicles that perform complex tasks and maneuvers

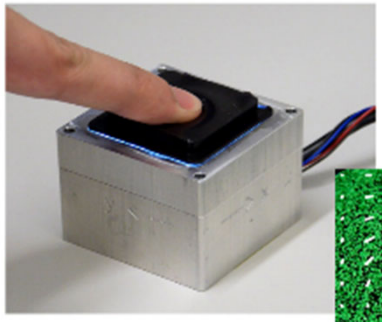
Examples of Research Projects

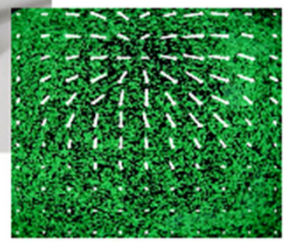
Vision-based robotic skins

Soft inflatable robotics

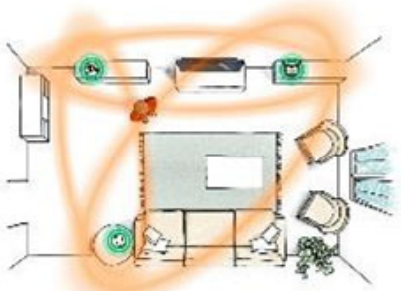


Co-ordination of robot swarms



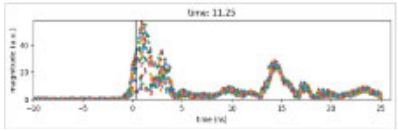


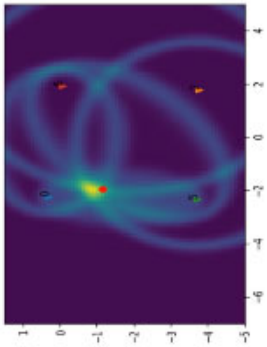
Machine learning for tactile sensing



Radar networks

UWB localization





UWB radar networks

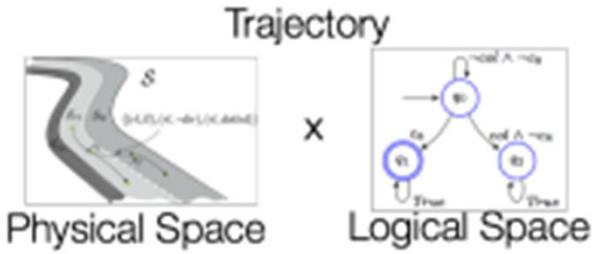
Prof. Dr. Emilio Frazzoli

- **Affiliation:**
  - D-MAVT
    - Institute for Dynamic Systems and Control

- **Research Areas**
  - ***Autonomous Vehicles***
    Enable vehicles such as cars and airplanes to safely and reliably drive/fly themselves in an uncertain, dynamic world (public roads, national airspace).
  - ***Control of Transportation Systems***
    Advanced control and optimization methods to enable new concepts for large-scale transportation systems.
  - ***Theoretical foundations***
    Advance the state of the art in foundational areas such as Control Theory, Algorithmic Robotics, System Design and Optimization

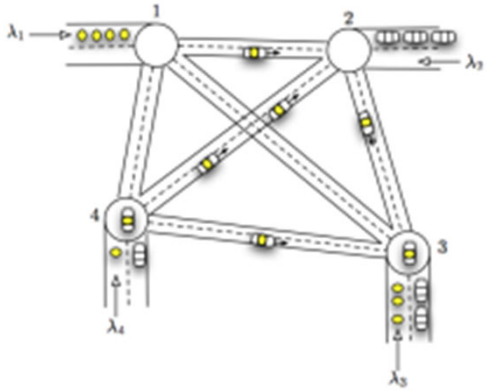
Examples of Research Projects

Planning and decision making for AVs



Planning with rules of the road

High-performance control

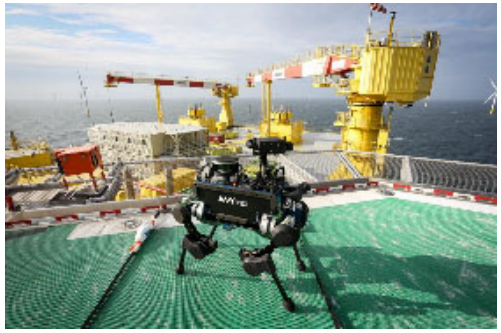


Mobility on Demand

Prof. Dr. Marco Hutter

- **Affiliation:**
  - D-MAVT
    - Institute of Robotics and Intelligent Systems
      - Robotic Systems Lab
- **Research Areas**
  - Planning and control for locomotion and manipulation
    - Machine learning, non-linear optimization and model-predictive control
  - Autonomous navigation and exploration
    - Environment perception and haptic sensing
  - System and actuator design
    - Quadrupedal robots, mobile manipulators, autonomous construction machines
  - Real-world applications
    - Search and rescue, industrial inspection and maintenance, construction and forestry,…

Examples of Research Projects



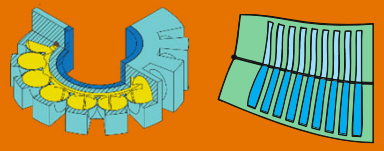
Prof. Dr. Robert Katzschmann

- **Affiliation:**
  - D-MAVT
    - Institute of Robotics and Intelligent Systems
      - Soft robotics
- **Research Areas**

  "Controlled Soft Robots Tackling Manipulation and Locomotion Challenges"
  - Underwater Soft Robots
  - Manipulation with Soft Hands
  - Real-time Simulation of Soft Robots
  - Model-based Control for Soft Robots
  - Scalable Fabrication of Soft Robots

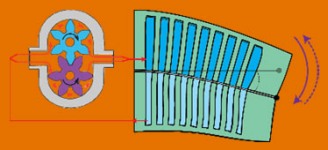
Examples of Soft Research Projects

Design

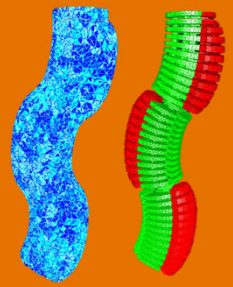


Fabrication

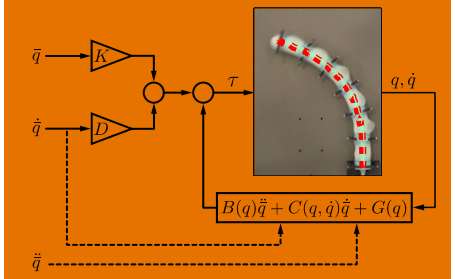
Actuation



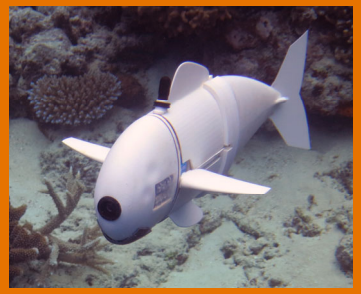
Modeling



Control

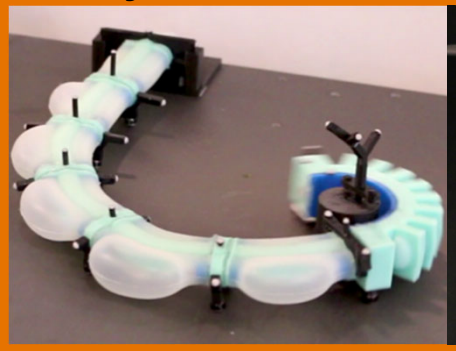


Biomimetic underwater robots



Adaptable hands

Dynamic soft manipulators



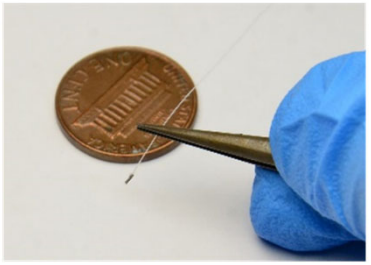
Prof. Dr. Brad Nelson

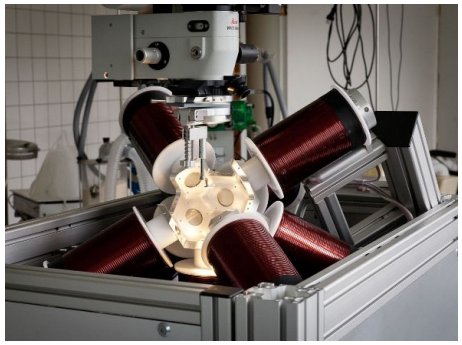
- **Affiliation:**
  - D-MAVT
    - Institute of Robotics and Intelligent Systems
      - Multi-Scale Robotics Lab

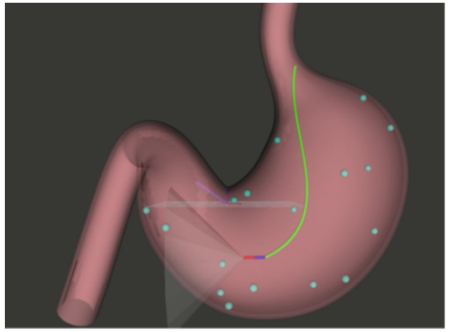
- **Research Area**
  - Micro and Nano Robotics
    - Autonomous Micro and Nano Robots
      - Design and Fabrication
      - Localization, Locomotion, Control
      - Biomedical Applications
    - Micro and Nano Manipulation
      - Sensor and Actuator Development
      - Fluidic and Self Assembly
    - Applications in Biology and Biomedical Engineering

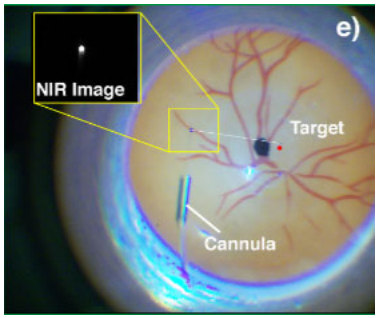
Examples of Research Projects

- Design and fabrication of biomedical micro-robots
- Soft robotics for medical applications
- Magnetic manipulation for intra-body navigation





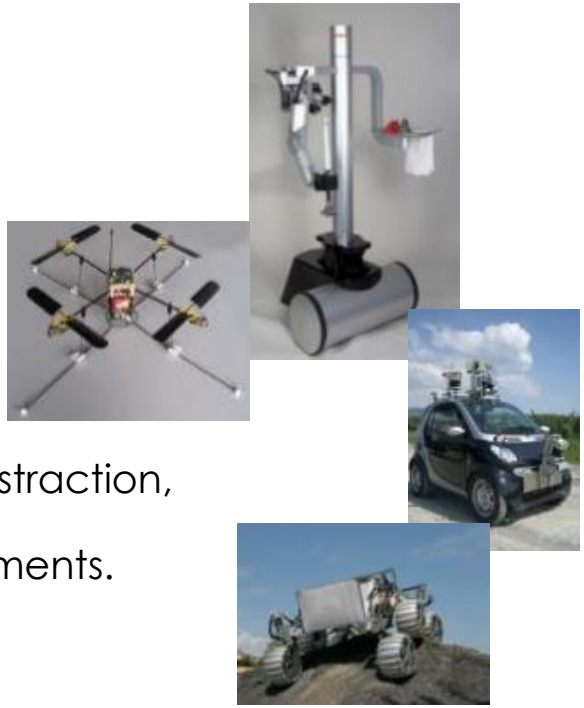




Prof. Dr. Roland Siegwart

- **Affiliation:**
  - D-MAVT
    - Institute of Robotics and Intelligent Systems
      - Autonomous Systems Lab

- **Research Area**
  - Mission and Dedication
    - To create intelligent robots and systems that operate autonomously in complex and dynamic environments.
  - Research Focus
    - Novel robot concepts that are best adapted for ground, air, or water based applications.
    - New algorithms for perception, localization, abstraction, mapping, and path planning that will enable autonomous operation in challenging environments.



ASL – ETH Zurich

https://www.youtube.com/user/aslteam

Autonomous Delivery Robots and Cars
Visual navigation and autonomous operation in city environments

Unmanned Aerial Vehicles
Design, control and fully autonomous operation in complex environments

Solar Airplanes
Continuous flight for long-term environment monitoring

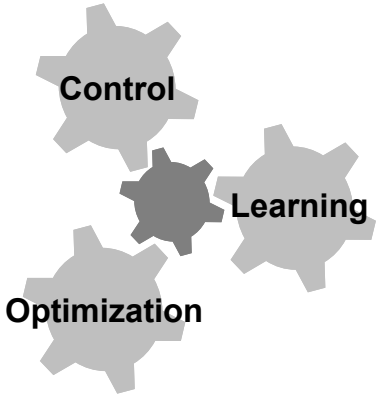
Underwater Robots
Design and autonomous navigation of underwater robots in rivers

Mobile Manipulation
Object handling for manufacturing, logistics, and e-commerce

Service Robots
Navigation and transportation in our daily environment

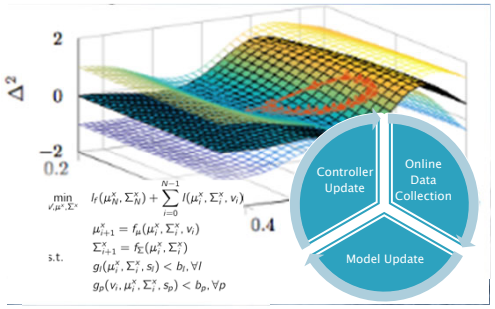
Prof. Dr. Melanie Zeilinger

- **Affiliation:**
  - D-MAVT
    - Institute for Dynamic Systems and Control
- **Research Areas**
  - Systems and Control Theory
    - Distributed Control of System Networks
    - Safe Learning-based Control
  - Optimization Methods
    - Real-time Methods for Control
  - Application to Robotic and Human in the Loop Control Systems

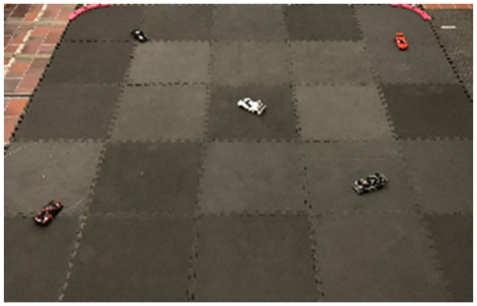


Examples of Research Projects

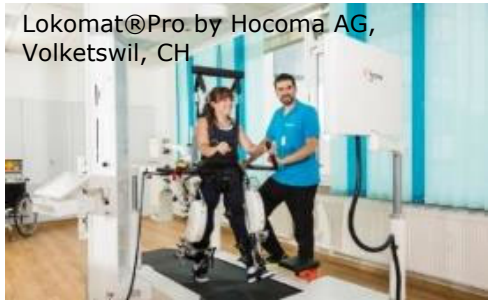
Safety Filters for Learning-based Control



Predictive Control under Uncertainty



Cooperative Multi-Agent Systems



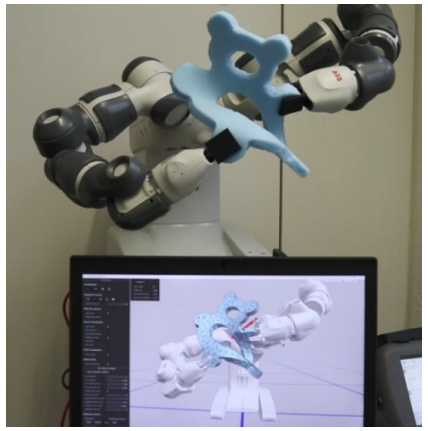
Personalized Control Systems

Prof. Dr. Stelian Coros

- **Affiliation:**
  - D-INFK
    - Computational Robotics Lab (CRL)

- **Research Area**
  - Engineering meets AI:
    - Algorithmic approaches to designing compliant robots
    - Exploiting multi-material 3D printing to create new types of robotic materials
  - Computational models of motor control
    - Locomotion (wheeled, legged, hybrid, compliant systems), manipulation (both rigid and deformable objects), mobile manipulation, human-robot interaction, learning and optimal control methodologies

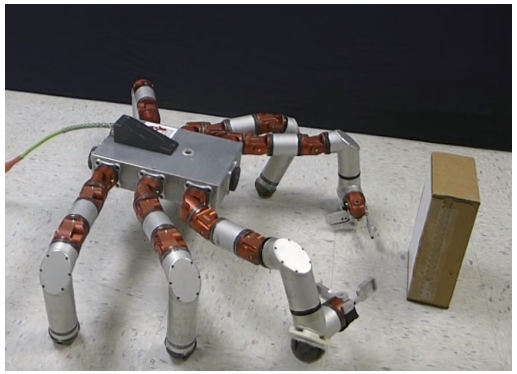
Examples of Research Projects (http://crl.ethz.ch/)



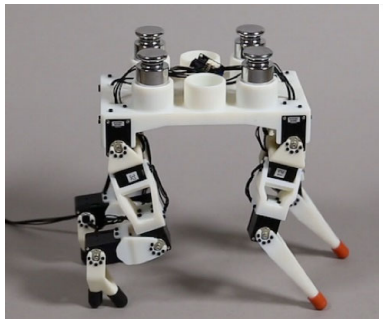
soft object manipulation

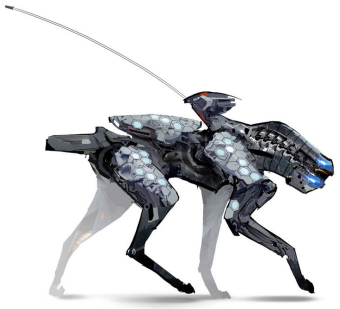
collaborative robots

human-robot interaction

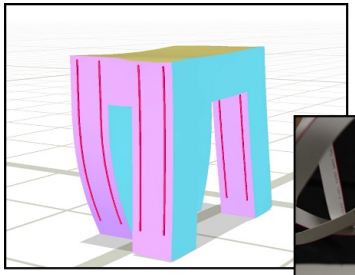


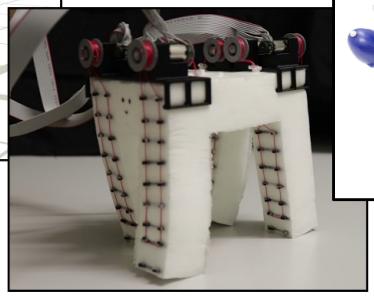
mobile manipulation





towards increasingly life-like legged robots





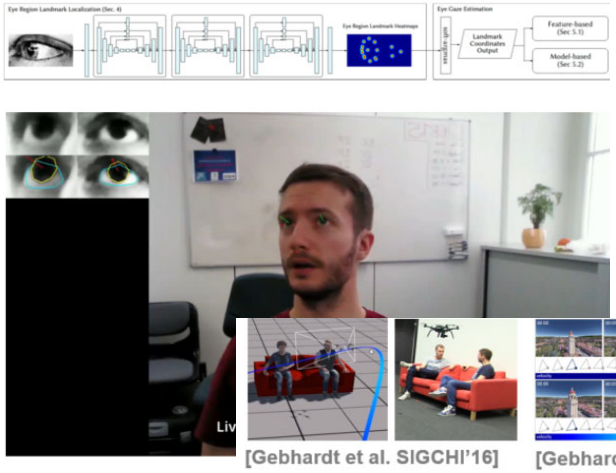
soft robotics

Prof. Dr. Otmar Hilliges

- **Affiliation:**
  - D-INFK
    - Institute(s) for Pervasive Computing & Visual Computing
      - Advanced Interactive Technologies Lab
- **Research Areas**
  - Intersection of machine learning, computer vision and robotics
  - Deep learning for machine perception of human activity
  - Applications in interactive systems and human-robot interaction

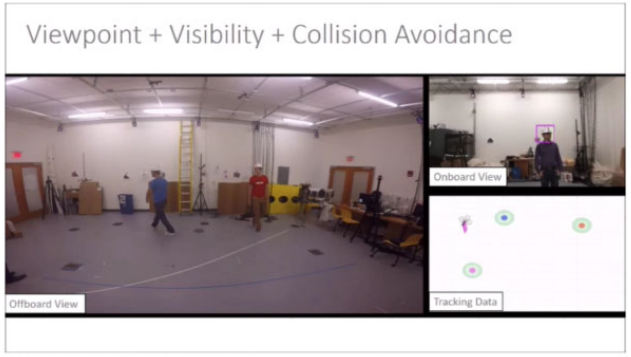
Examples of Research Projects: Perception and Real-time control

[Spurr et al. CVPR '18]

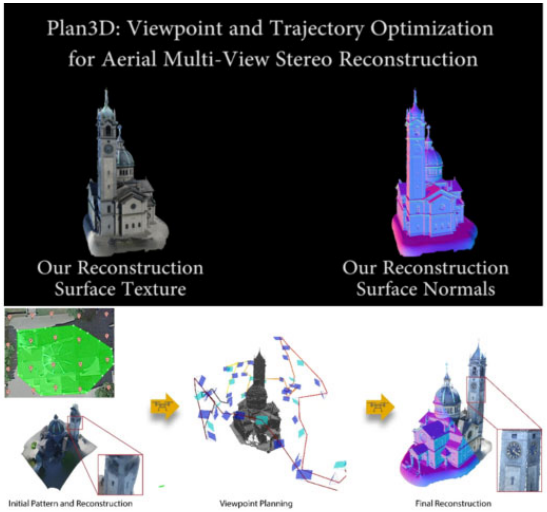


[Gebhardt et al. SIGCHI'16]

[Gebhardt et al. WIP]



[Naegeli et al. RA-L '17]



[Hepp et al. in submission Siggraph '18]

Prof. Dr. Marc Pollefeys

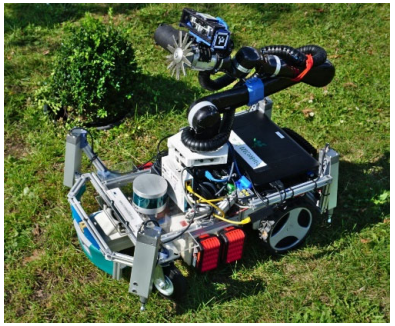
- **Affiliation:**
  - D-INFK
    - Institute for Visual Computing
      - Computer Vision and Geometry Lab

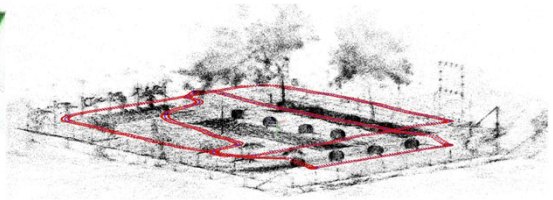
- **Research Area**
  - Computer Vision
    - 3D Modeling from Images
    - 3D Sensing, Sensor Calibration, Omni-Directional Vision
    - Real-Time Computer Vision
  - Robot Vision
    - Visual Simultaneous Localization and Mapping
    - Mapping and Navigation for MAV, humanoid robots and cars

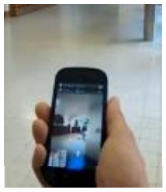
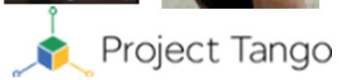
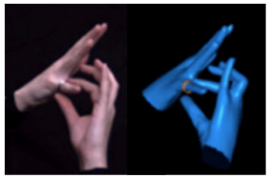
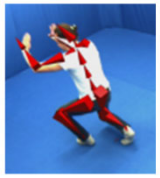
Examples of Research Projects

- Autonomous Micro Air Vehicles
- Autonomous Driving
- Visual Localization
- 3D Mapping
- 3D Modeling of Interacting People
- Real-Time Embedded Computer Vision







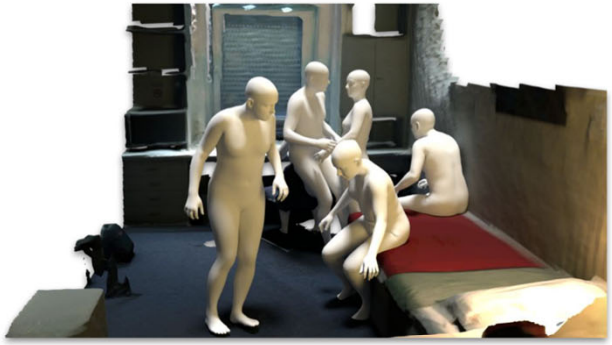

Prof. Dr. Siyu Tang

- **Affiliation:**
  - D-INFK
    - Institute for Visual Computing
      - Computer Vision and Learning Group
- **Research Areas:**
  - Intersection of computer vision, machine learning and optimisation with focus on analysing and modelling people
    - People detection and tracking
    - Action understanding
    - Generative models of 3D human
    - Representation learning
    - Discrete optimisation for image and video analysis

Examples of Research Projects

People detection and tracking

3D human modelling



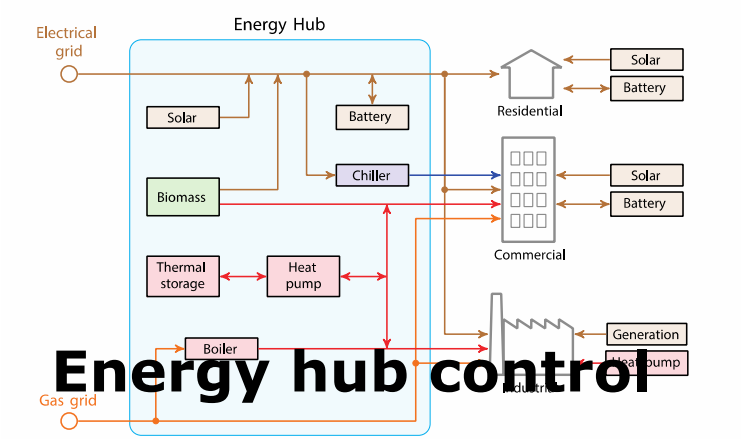
Generative models of human scene interaction

Prof. Dr. Roy Smith

- **Affiliation:**
  - D-ITET
    - Automatic Control Lab

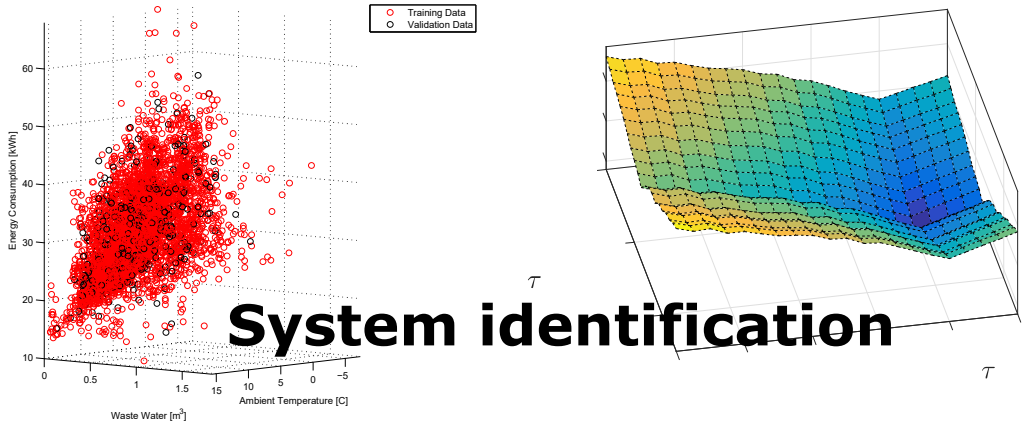
- **Research Areas**
  - System modeling and identification
  - Distributed control systems
  - Energy management in buildings and energy hubs
  - Autonomous kites for power generation
  - Robust control theory and applications
  - Thermoacoustic machines

Examples of Research Projects



Energy hub control

Thermoacoustic machines



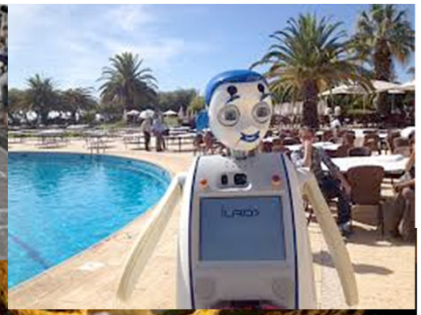
System identification

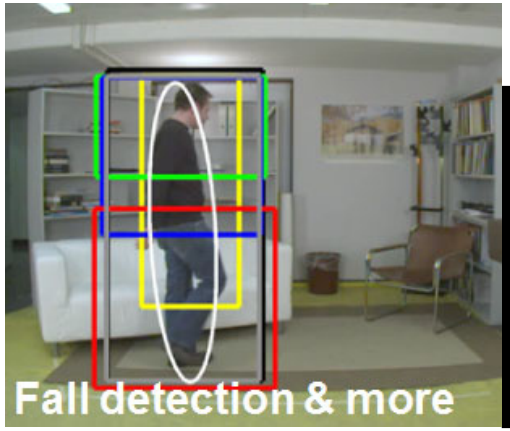
Cooperative control testbed

Prof. Dr. Luc van Gool

- **Affiliation:**
  - D-ITET
    - Computer Vision Laboratory
- **Research Areas**
  - Computer Vision
    - 3D modeling from images or with structured light
    - Object (class) recognition
    - Tracking and gesture analysis
    - Combinations of the above
  - Robot Vision
    - Autonomous vehicles
    - Medical robots
  - Surveillance
    - Anomaly detection

Examples of a Research Projects





Prof. Dr. Roger Gassert

Using robotics, wearable sensors and non-invasive neuroimaging to explore, assess and restore sensorimotor function

Affiliation:

- D-HEST
  - Institute of Robotics and Intelligent Systems
    - Rehabilitation Engineering Laboratory

Research Areas

- Haptics and Physical Human-Machine Interaction
  - Interaction control, sensor/actuator design and characterization
- Neuro-robotics and Rehabilitation
  - Robot/neuroimaging-assisted therapy, devices for home therapy
- Assistive Technology
  - Exoskeletons, brain-computer interfaces

Examples of Research Projects

Explore

- **sensorimotor neuroscience & neuromechanics**

Assess

- **assessment tools & objective metrics**
- **motor and somatosensory function**

Restore

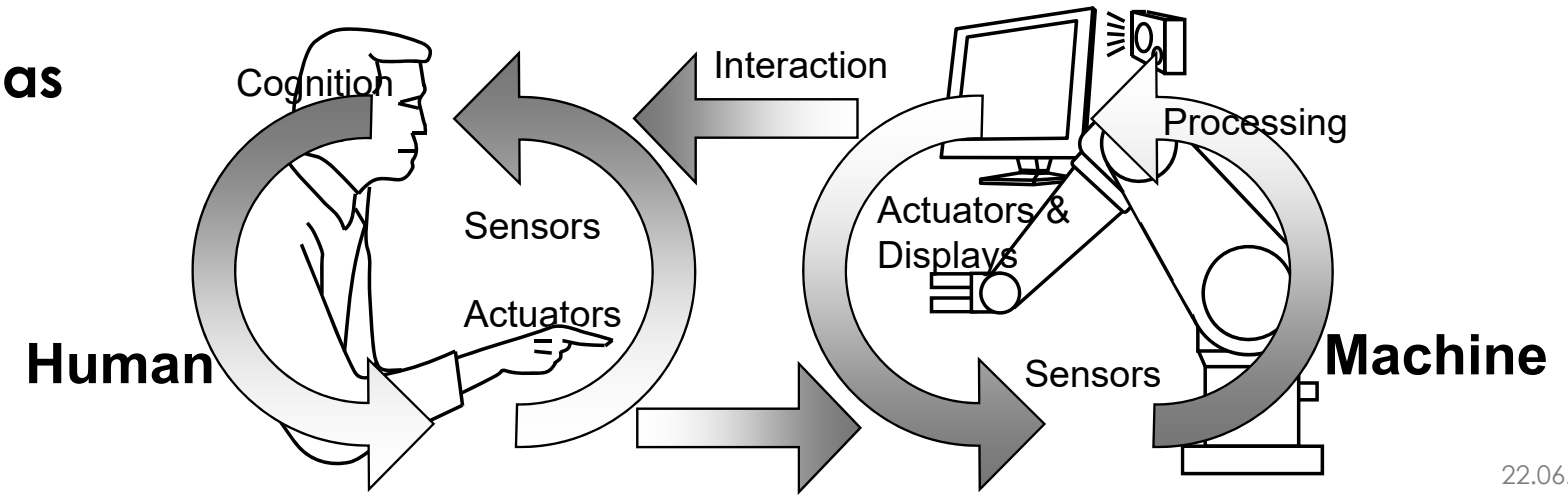
- **minimally-supervised therapy & assistance**
- **wearable robotics & neuroimaging**

RELAB Engineering for Independence

Prof. Dr. Robert Riener

- **Affiliations:**
  - D-HEST, ETH Zurich
    - Institute of Robotics and Intelligent Systems
      - Sensory-Motor Systems Lab
  - Medical Faculty, University of Zurich
    - University Hospital Balgrist, Zurich

- **Research Areas**

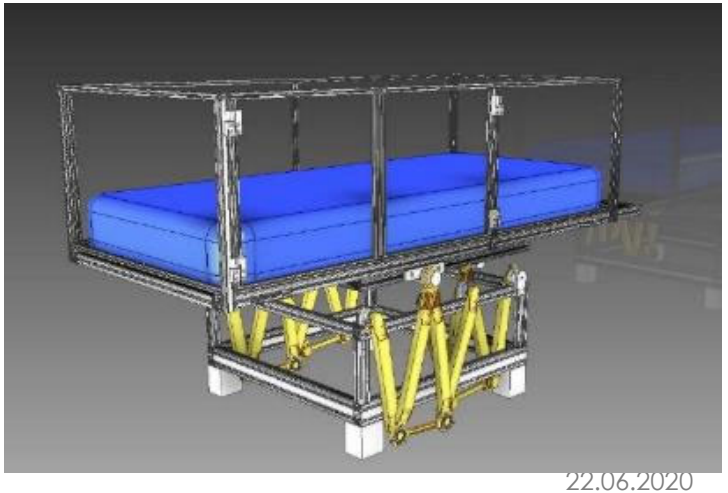


Research Projects

Rehabilitation Robotics

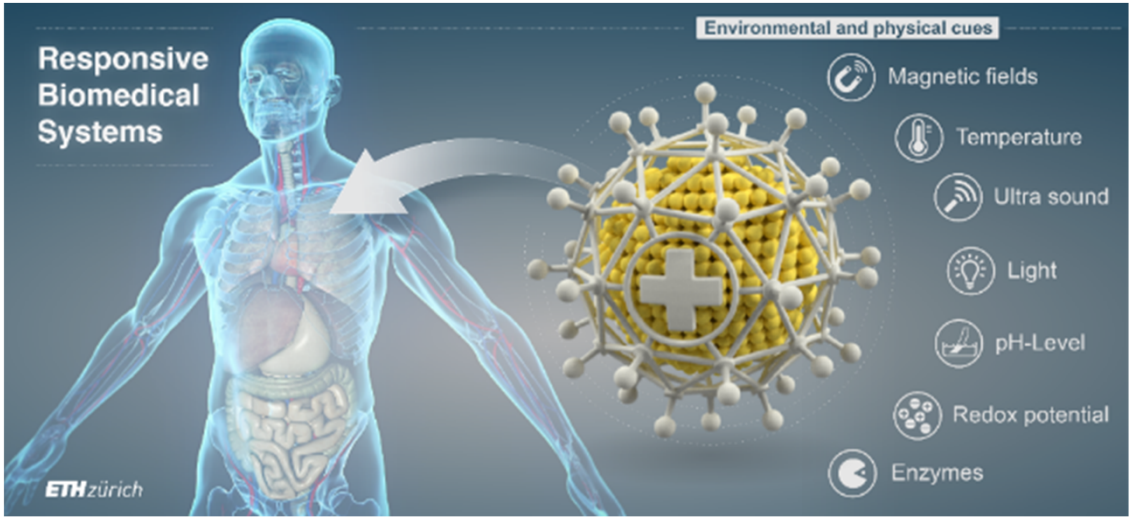
Wearable Exoskeletons

Somnomat for improved sleep



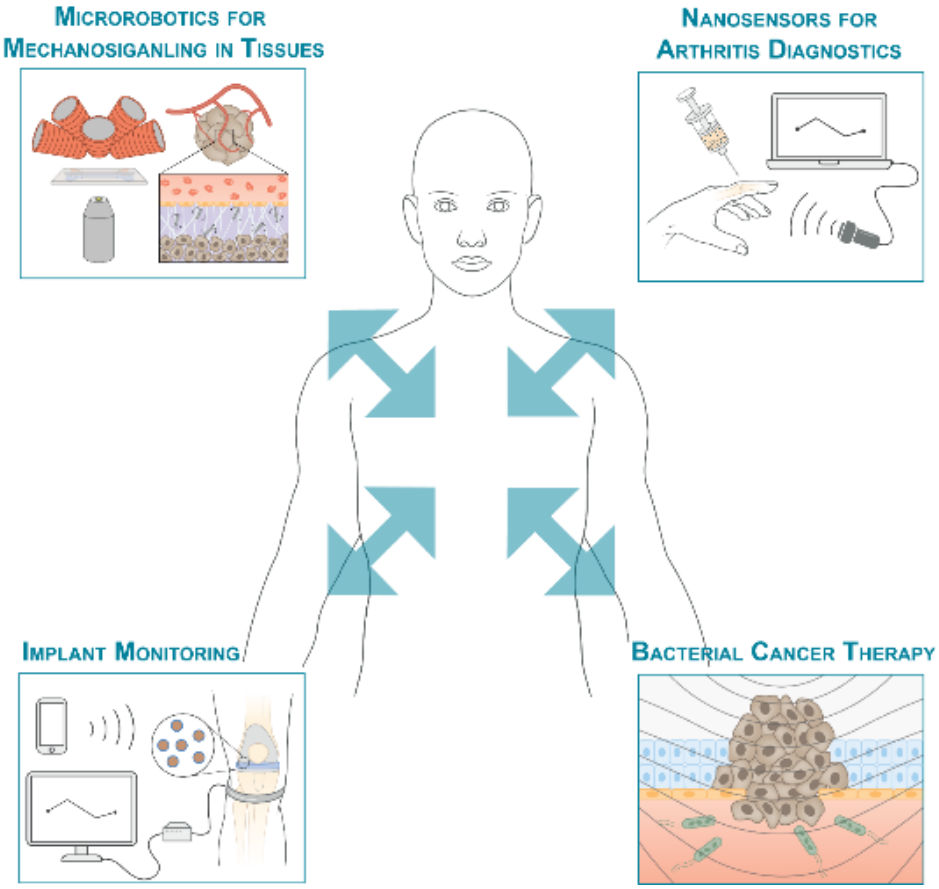
Prof. Dr. Simone Schürle

- **Affiliation:**
  - D-HEST
    - Institute of Translational Medicine
      - Responsive Biomedical Systems Laboratory
- **Research Areas**
  - Design and Fabrication of micro- and nanosystems
    - Diseases diagnostics
    - Localized therapeutic delivery
    - Therapy monitoring
  - Engineering of companion instrumentation for signal transduction and processing



Examples of a Research Projects

Remote control of microrobots in tissue to probe and sense local biomechanics



Inductance and acoustic-based detection of micro- and nanosensors as reporters for early stages of arthritis

Wireless detection of local infections through smart implant coatings

Swarm control of magnetic bacteria for cancer therapy