ETH zürich

Walking and Flying Robots for Challenging Environments

Roland Siegwart, ETH Zurich
www.asl.ethz.ch
www.wysszurich.ch

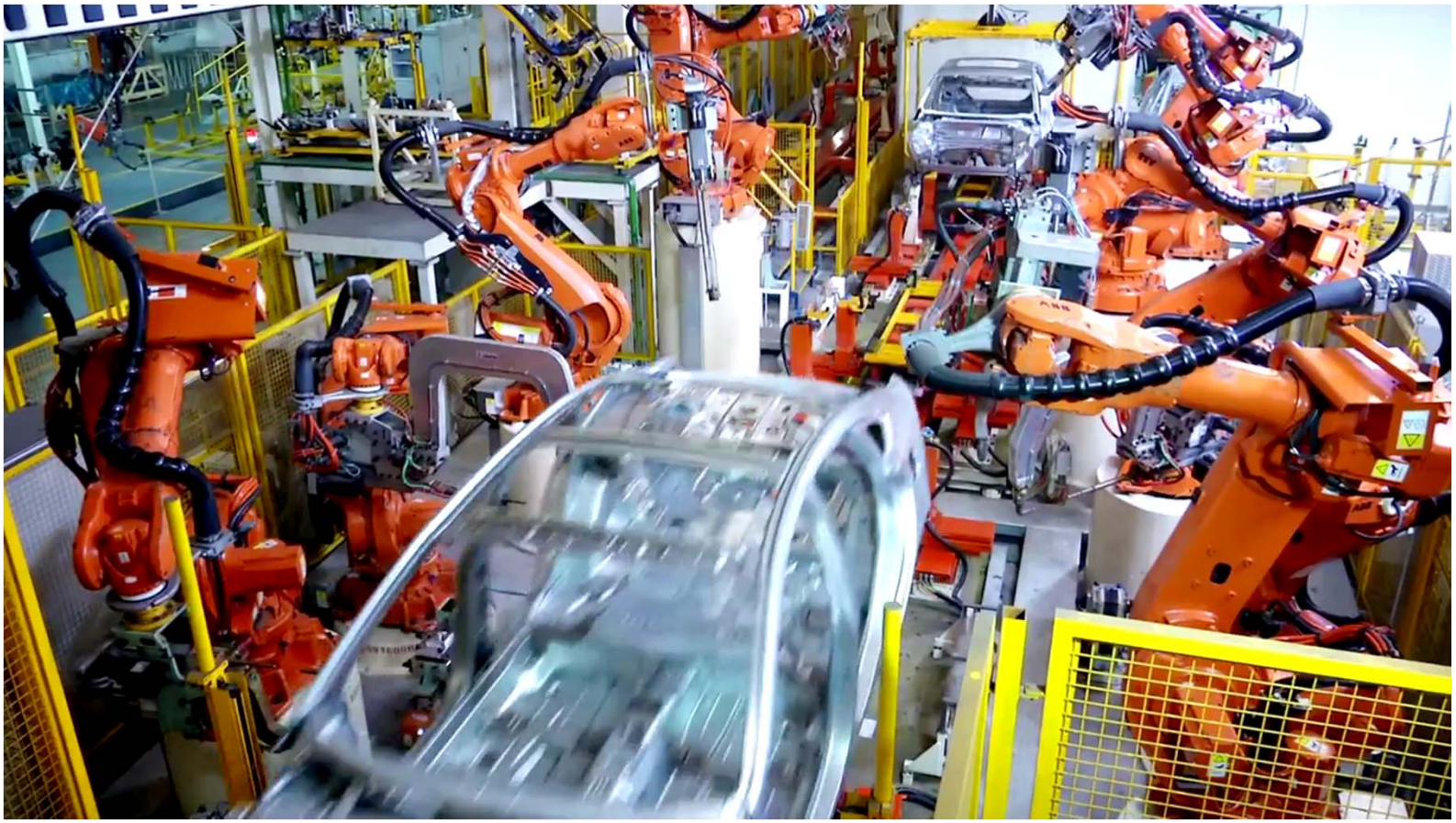
ICINCO 2016
13th INTERNATIONAL CONFERENCE ON INFORMATICS IN CONTROL, AUTOMATION AND ROBOTICS

Lisbon, Portugal, July 29, 2016

Content

- Introduction | *The next generation of robots*
- Robot Design | *Examples from ASL at ETH Zurich*
- Mobile Robot Navigation | *from perception to autonomous navigation*
- Application Fields

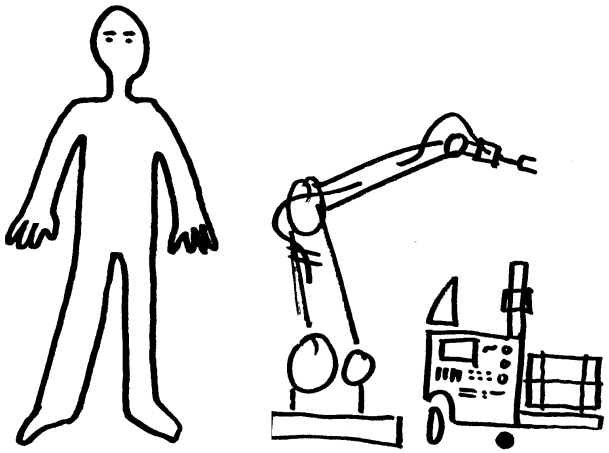
Robotics today (Changan-Ford China)



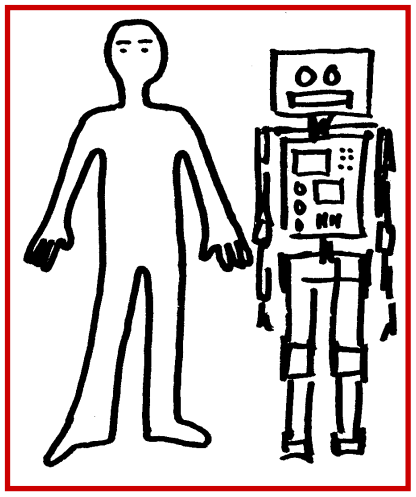
https://www.youtube.com/watch?v=SeIoQy0oXjI

Next generation of Robots

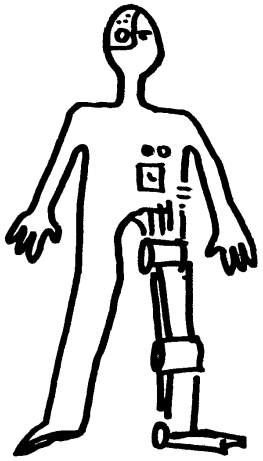
| mobile, smart, connected, adaptive and closer to humans



Industrial Robots



Service and Personal Robots



Cyborgs

Robotics | Key Directions

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

Autonomous Systems Lab @ ETH

Institute of Robotics and Intelligent Systems
Prof. Dr. Roland Siegwart

~ 40 researcher (PhDs, Postdocs, ...)
~ 60 master students
~ 10 startups





- **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.

Navigation Design

Research Fields

Autonomous Cars
Visual navigation and autonomous operation in city environments

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

Solar Airplanes
Continuous flight for long-term environment monitoring

All Terrain Robots
Design and collaborative navigation of flying and ground robots

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

Service Robots
Navigation and transportation in our daily environment

Robotics Start with the Design

Rolling, Swimming, Walking and Flying Robots

Ultimate Rolling Robots – designed by students

rezero (2010)

| the ball balancing robot

https://www.youtube.com/watch?v=ACohrH64YKs

BeachBot (2014, with Disney)

| the beach artist

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

Vertigo (2015 with Disney)

| the ultimate wall climber

https://www.youtube.com/watch?v=KRYT2kYbgo4

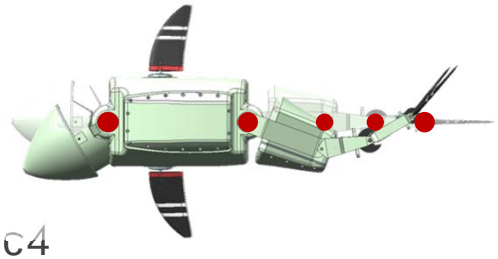
Scalevo (2015)

| the stair-climbing wheelchair

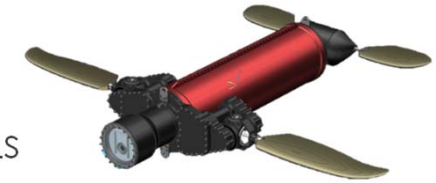
https://www.youtube.com/watch?v=3lb_8nmy90c

Underwater Robots – designed by students

Naro (2009)
| the tuna robot
https://www.youtube.com/watch?v=L61O2CmZCc4

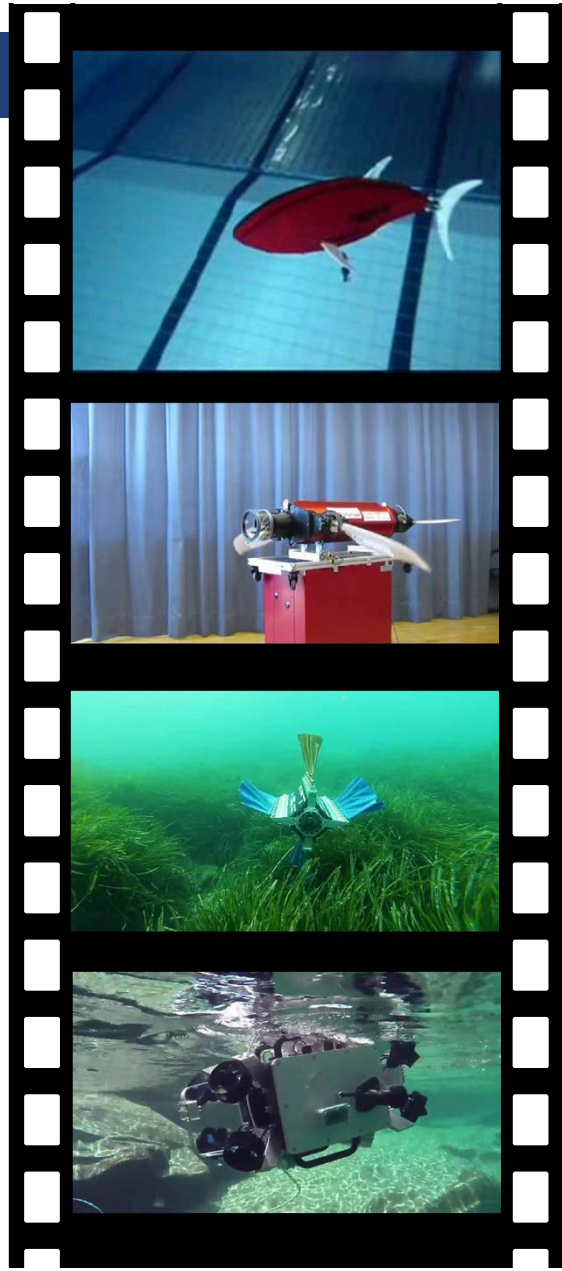


Taratuga (2012)
| the turtle robot
https://www.youtube.com/watch?v=pqy_NSHcGLs



Sepios (2014, with Disney)
| the Kalmar robot
https://www.youtube.com/watch?v=GeCLL2RWV1c

Scubo (2016, with Disney)
| the agile underwater robot
https://www.youtube.com/watch?v=-g2O8e1j3fw



Walking Robots – serial elastic actuation

ALOF (2008)

| the versatile walker

https://www.youtube.com/watch?v=F5HsFyirhZI

StarlETH (2010)

| the quadruped with serial elastic actuation

https://www.youtube.com/watch?v=7qj65Ta7tLE

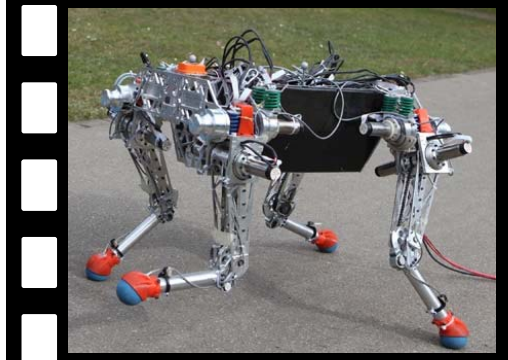
AnyBot (2015)

| the ultimate quadruped

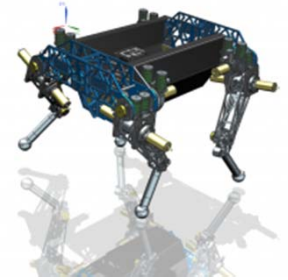
https://www.youtube.com/watch?v=El1zBTYpXW0

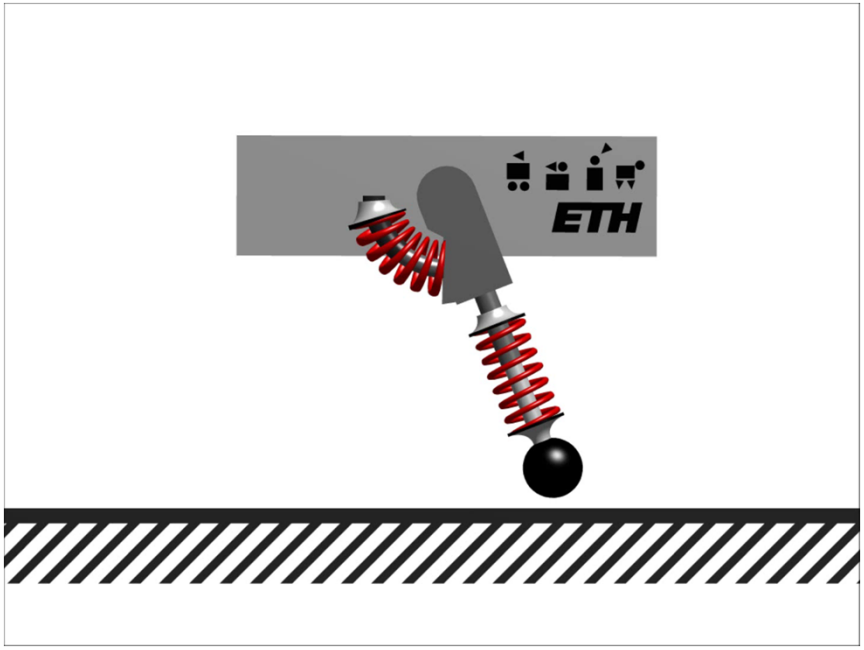
RSL Robotic Systems Lab

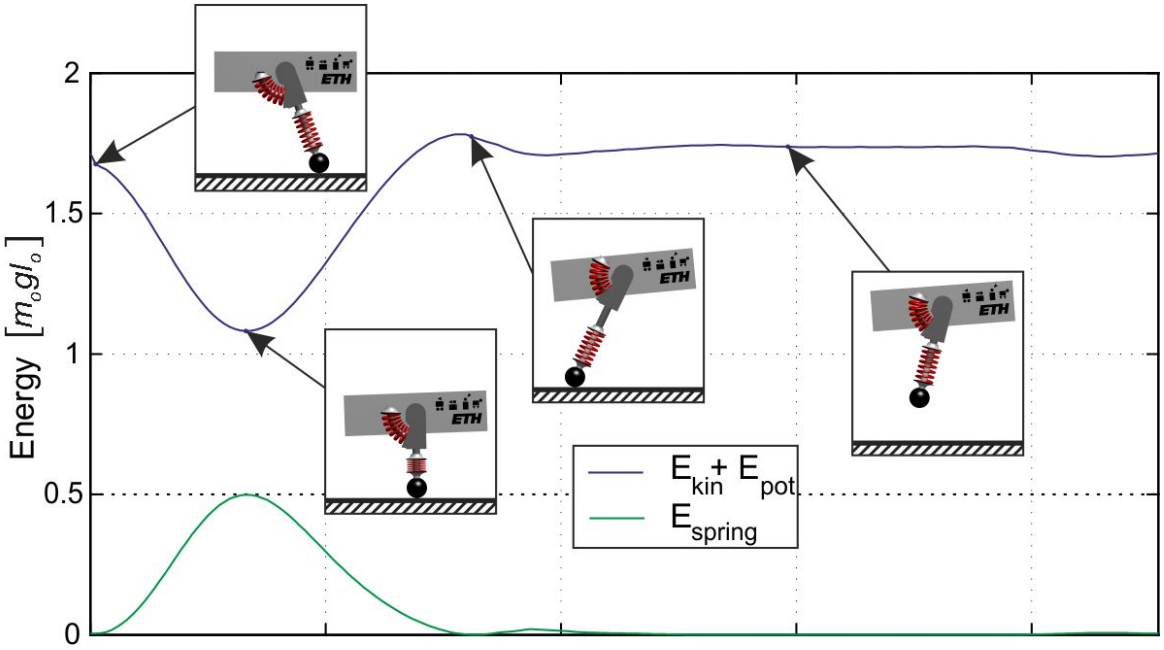
Prof. Marco Hutter



Efficient Walking and Running | serial elastic actuation

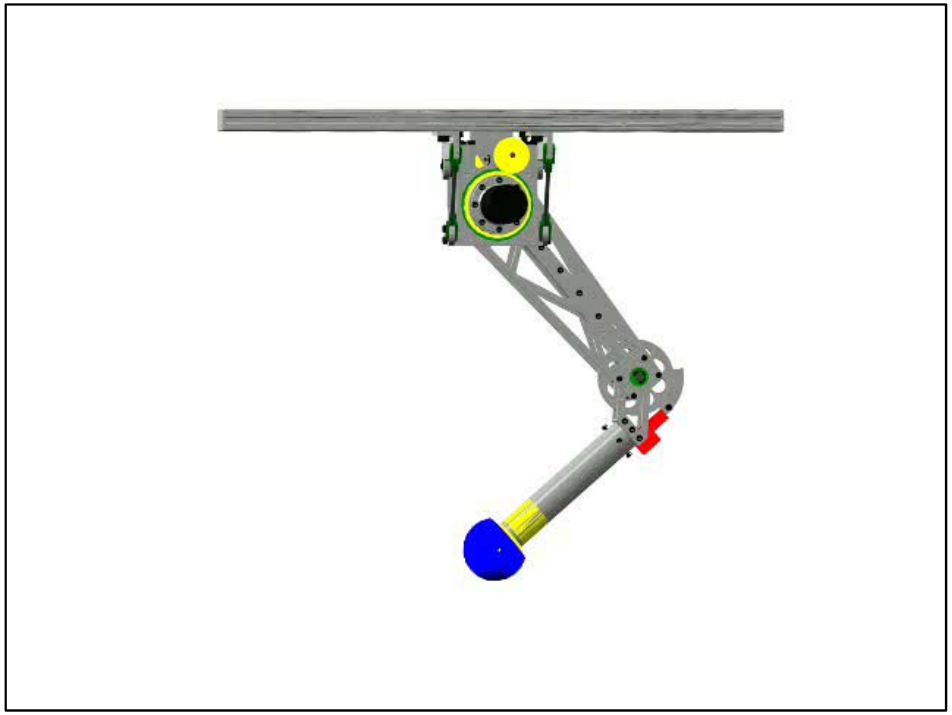


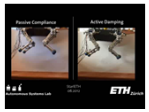


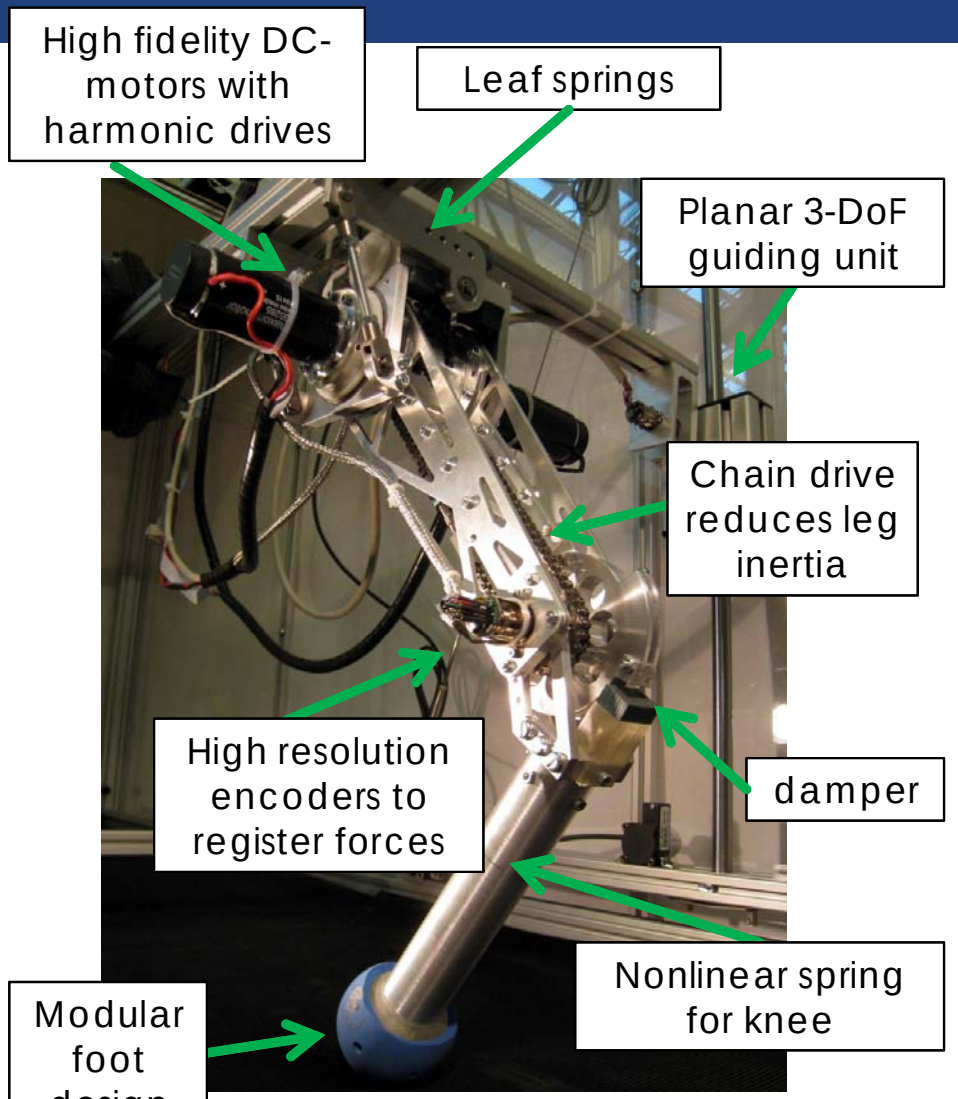


https://www.youtube.com/watch?v=6igNZiVtbxU

StarlETH | Leg Design for Dynamic Walking







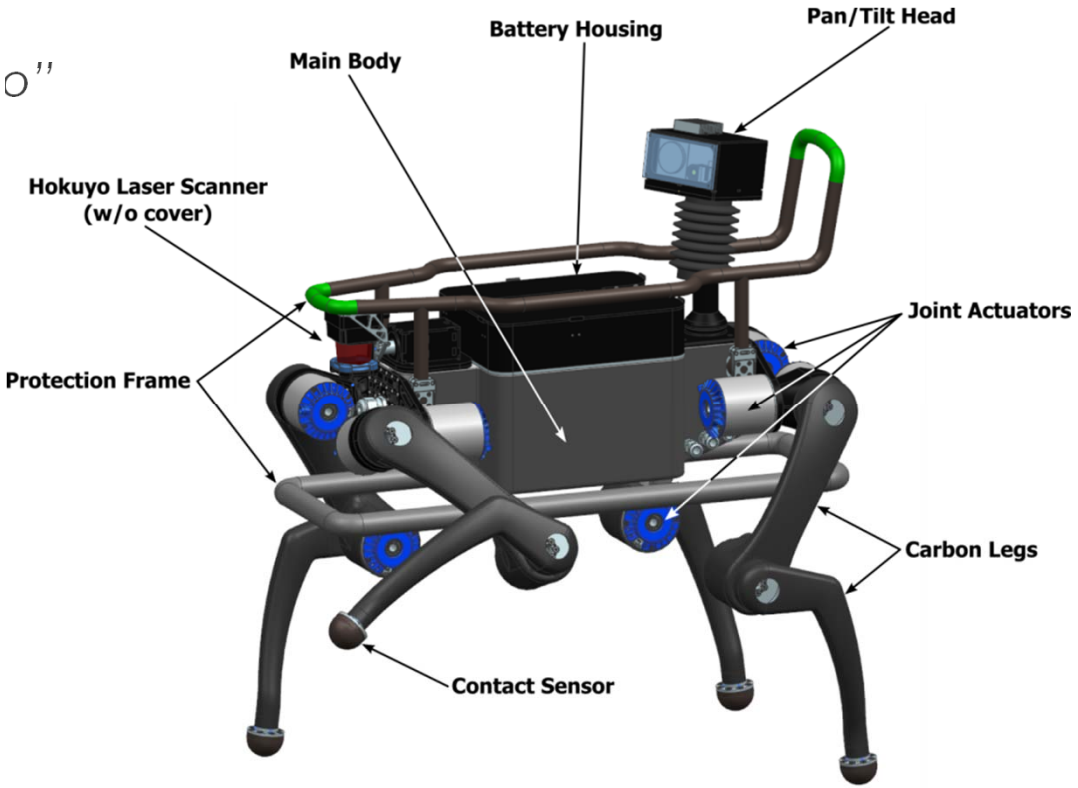
ANYmal

an electrically actuated dog for real-world scenarios

RSL Robotic Systems Lab

Prof. Marco Hutter

- High mobility
  - *"to go where today only humans can go"*
- 10 kg of payload
- 2 h of continuous operations



https://www.youtube.com/watch?v=El1zBTYpXW0

Flying Robots | new ways of flying

OS4 (2003)
| pioneering quadrotors

https://www.youtube.com/watch?v=vSvte6_74tU&index=34&list=PLJol3sa8g75RNJ0vALyl0BBfTNuhwWe1g

Reely (2009 – with Disney)
| the flying reel

https://www.youtube.com/watch?v=RF6OyKKmrX8

Skye (2012 – with Disney)
| the omnidirectional blimp

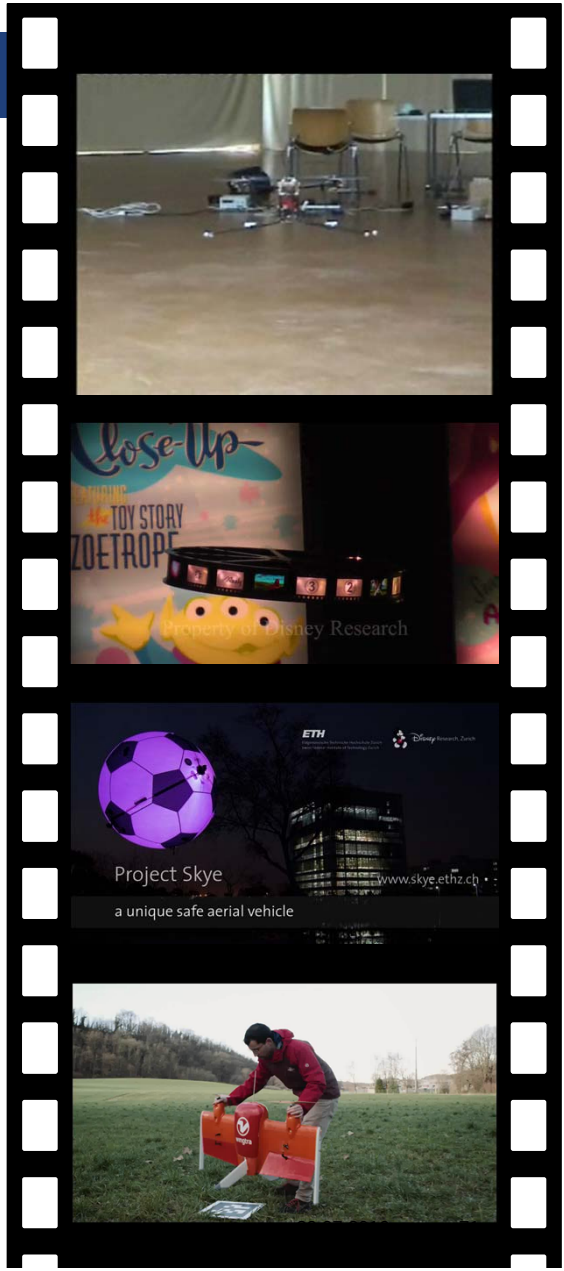
AEROTAIN

https://www.youtube.com/watch?v=qXvl3anK3w0

PacFlyer/wingtra (2013)
| the VTOL UAV

wingtra

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



Flying Robots – fixed wing

Skysailor (2008)

- pioneering continuous flights
- 3.2 m, 2.3 kg

https://www.youtube.com/watch?v=lU4BoEFOEKI

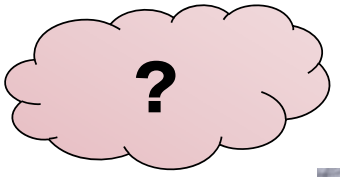
senseSoar (2012)

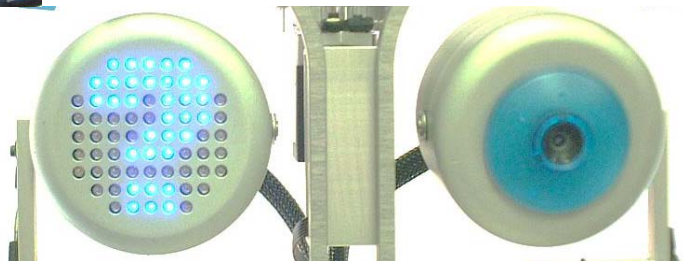
- robust and versatile solar plane
- 3 m, 3.8 kg

Atlantik Solar (2015)

- 81 hours non-stop in summer 2015
- 5.64 m, 6.2 kg

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



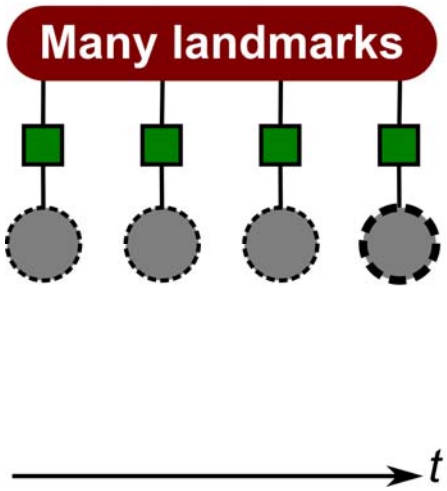


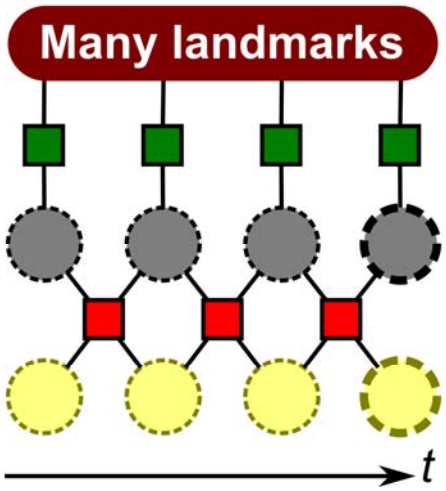
Mobile Robot Navigation

Localization, Mapping and Planning

OKVIS | Open Keyframe-based Visual-Inertial SLAM

(tight coupling of vision and IMU)



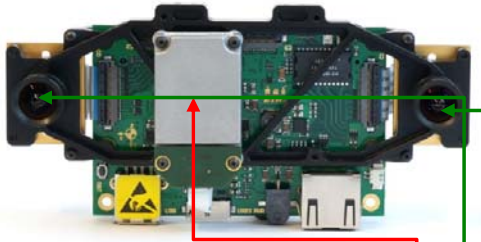


Pose

Speed / IMU bias'

Many keypoint measurements

IMU measure



$$J(\mathbf{x}) := \sum_{i=1}^{I} \sum_{k=1}^{K} \sum_{j \in \mathcal{J}(i,k)} \mathbf{e}_{\mathrm{r}}^{i,j,k\,T} \mathbf{W}_{\mathrm{r}}^{i,j,k} \mathbf{e}_{\mathrm{r}}^{i,j,k} + \sum_{k=1}^{K-1} \mathbf{e}_{\mathrm{s}}^{k\,T} \mathbf{W}_{\mathrm{s}}^{k} \mathbf{e}_{\mathrm{s}}^{k}.$$

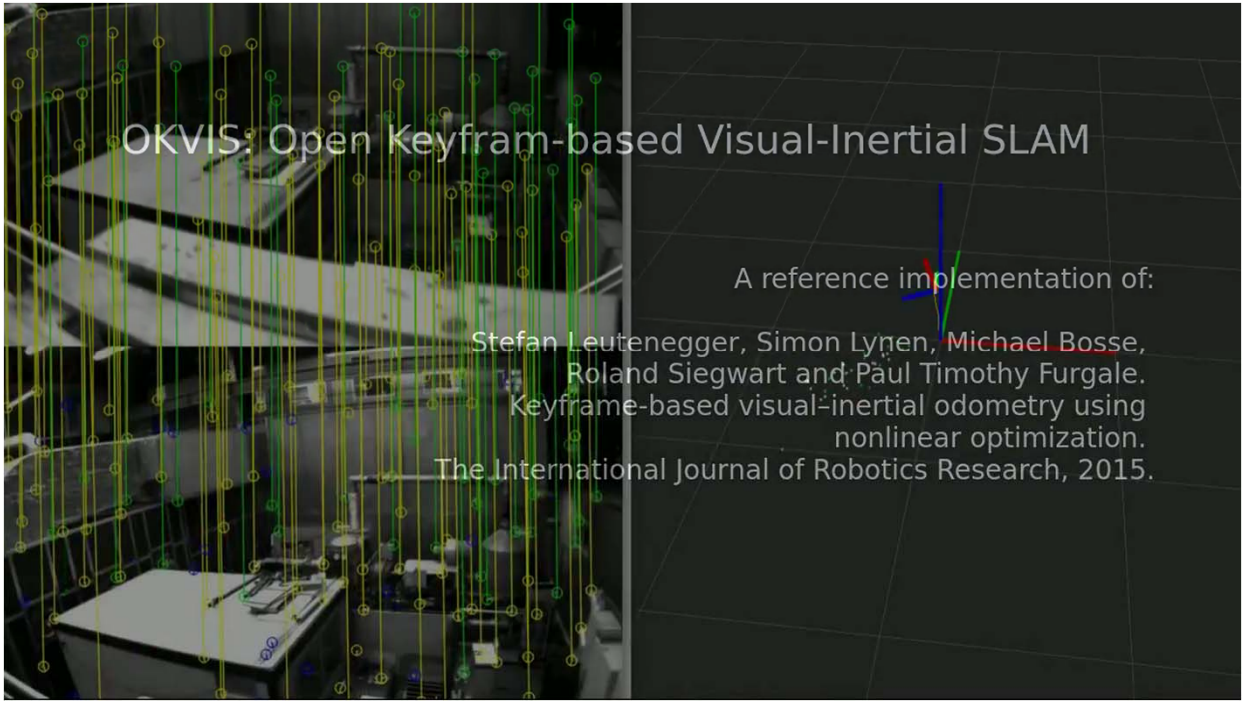
Cost — Reprojection errors (weighted) — IMU terms

i: camera index; *k:* camera frame index; *j:* landmark index.

OKVIS | Open Keyframe-based Visual-Inertial SLAM

(tight coupling of vision and IMU)

- motion of an assembly of Inertial Measurement Units (IMU) and N cameras to reconstructs the scene sparsely



“Seeing” | Visual-Inertial Motion Estimation

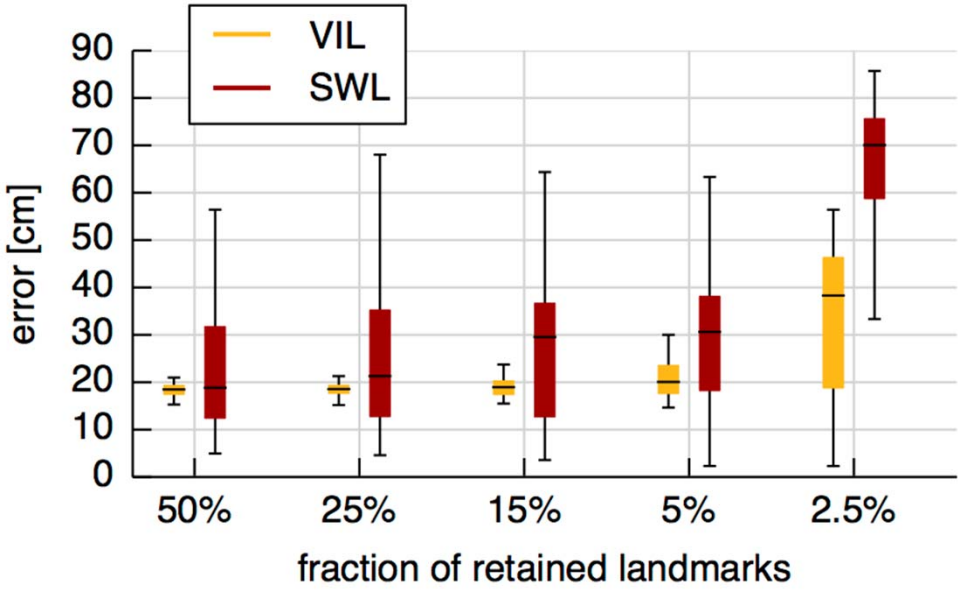
Google Project Tango

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

LL-VSLAM | Localization performance comparison

Google Project Tango

- Global localization error for different levels of map summarization



processing of odometry and localization landmarks:

VIL tightly coupled (proposed method)

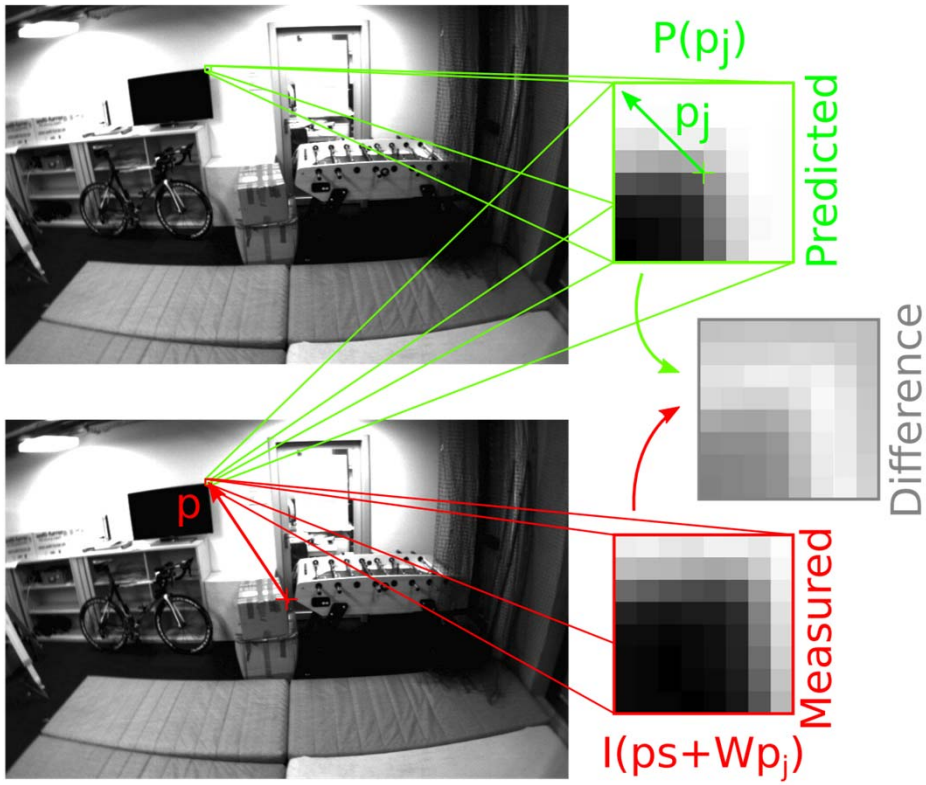
SWL loosely coupled approach

✓ The proposed visual-inertial localization algorithm performs well with heavily summarized maps

ROVIO | Robust Visual Inertial Odometry

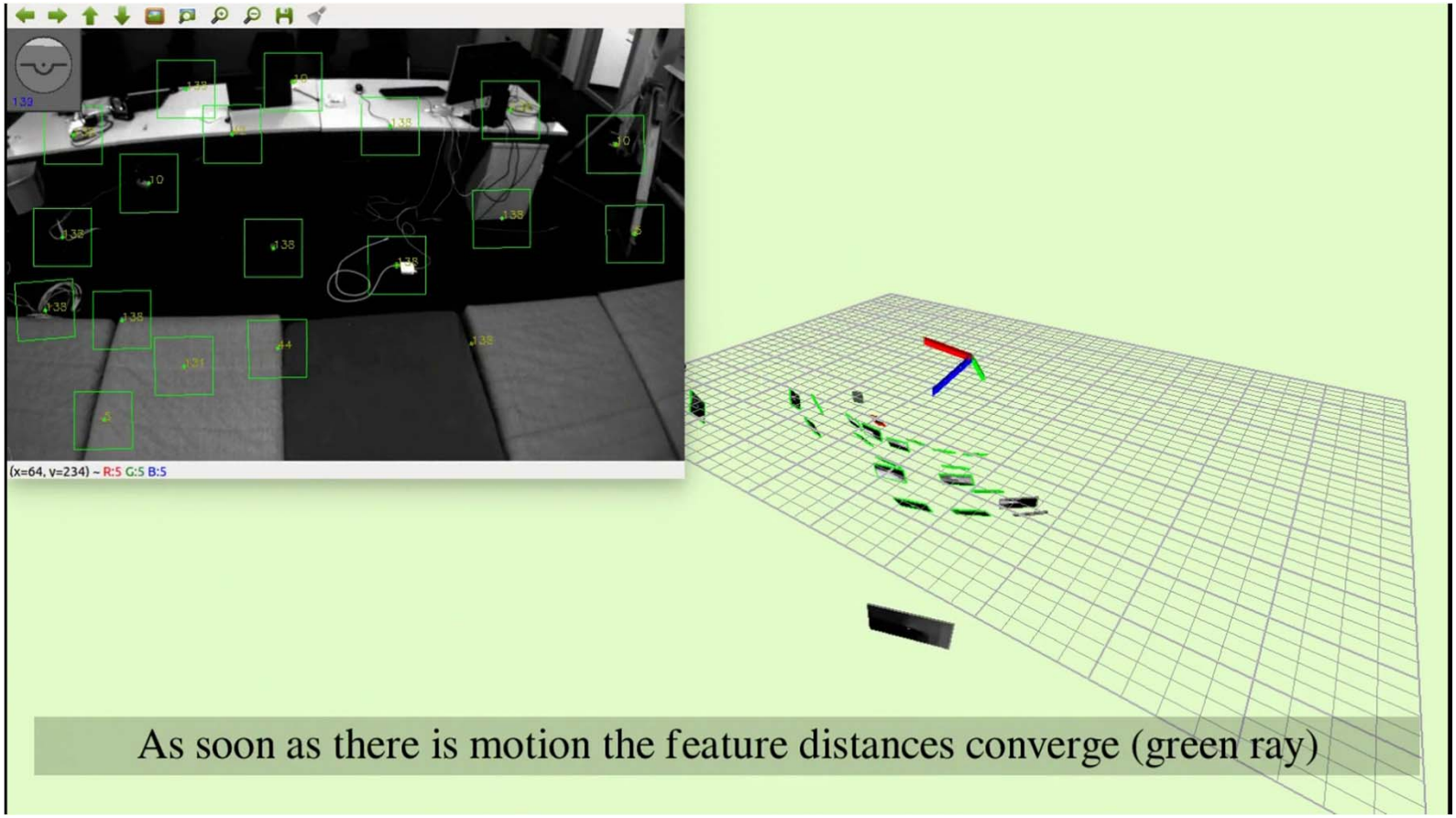
- robo-centric representation
- EKF based IMU-Vision fuses
- projected intensity errors (instead of reprojection errors)

- Procedure
  - feature detection & image patch is extracted
  - Derivation of an intensity based error terms
  - dimension reduction of error term by QR-decomposition directly used as Kalman filter innovation



ROVIO | Robust Visual Inertial Odometry

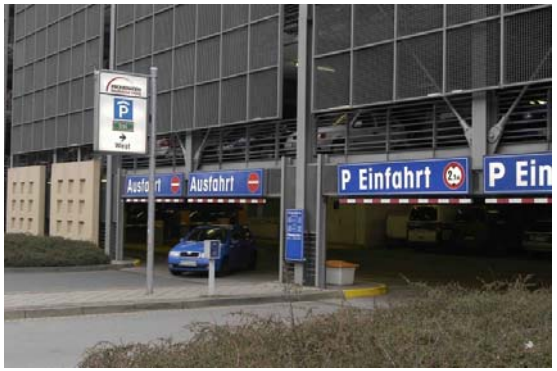
https://www.youtube.com/watch?v=ZMAISVy-6ao&list=PLJol3sa8g75RNJ0vALyl0BBfTNuhwWe1g&index=2



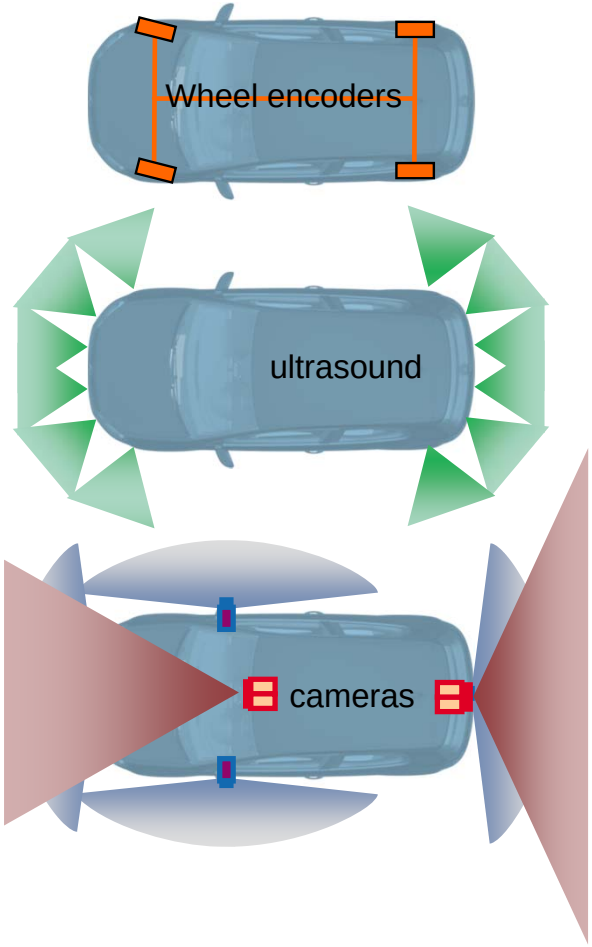
[M. Bloesch et al (2015). Robust Visual Inertial Odometry Using a Direct EKF-Based Approach, IROS]

V-Charge | Automated Valet Parking and Charging for e-Mobility

- Close-to-market sensor systems
  - vision, stereo vision, ultrasonic etc.
- Online localization and mapping
- Situation assessment
  - Street, pedestrians
- Path Planning
  - Global & local (collision avoidance)
  - Highly adaptive and predictive
    - dynamic obstacles and their potential trajectory.



V-Charge | autonomous car using close-to-market sensors



ETH zürich

VOLKSWAGEN
AKTIENGESELLSCHAFT

BOSCH

UNIVERSITY OF OXFORD

UNIVERSITÀ DEGLI STUDI DI PARMA

Technische Universität Braunschweig

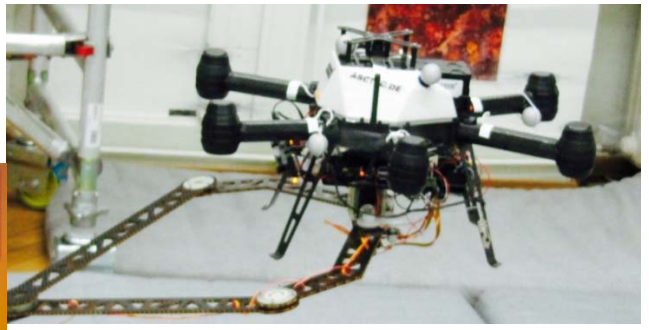
V-Charge | Vision and Results

https://www.youtube.com/watch?v=7xQfKTAtyNU

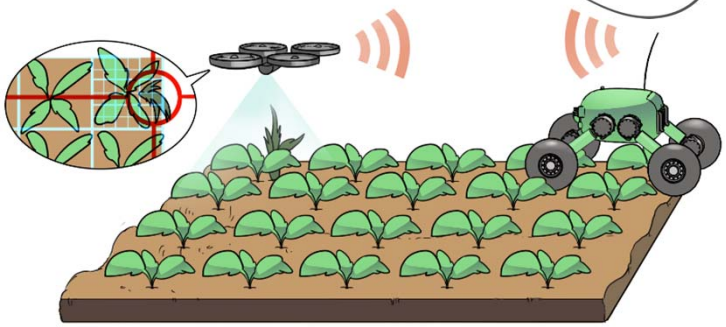
Flying Robots | EU-Projects

European Robotics Challenges

AERO WORKS



Flourish



SHERPA

www.sfly.ethz.ch/

UAV | vision only navigation

- Vision-inertial navigation (one camera and IMU, **GPS denied**)
- Fully autonomous with on-board computing
- Scale estimation
- Feature-based visual SLAM
  - robust against lighting changes and large scale changes

https://www.youtube.com/watch?v=vHpw8zc7-JQ

UAV | collision avoidance and path planning

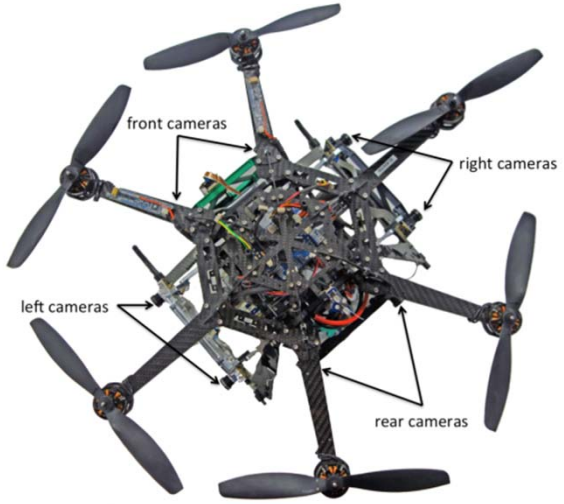
- Real time 3D mapping (on-board)
- optimal path planning considering localization uncertainties

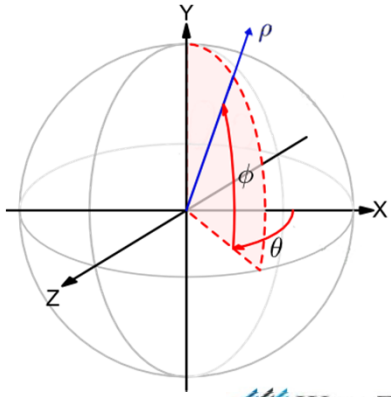
https://www.youtube.com/watch?v=95XGvEs9iTs

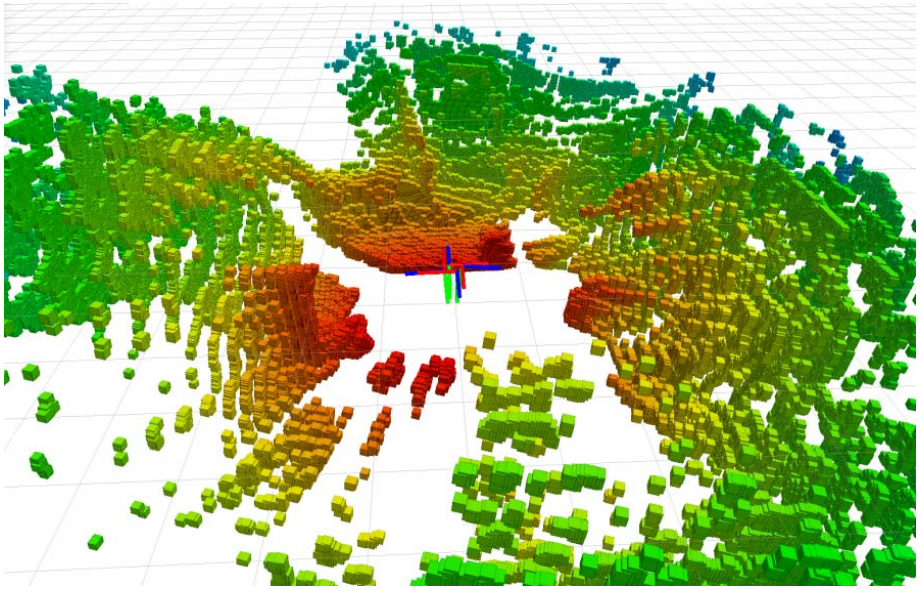
https://www.youtube.com/watch?v=D6uVejyMea4

https://www.youtube.com/watch?v=-cm-HkTI8vw

Omnidirectional 3D | visual obstacle detection and avoidance





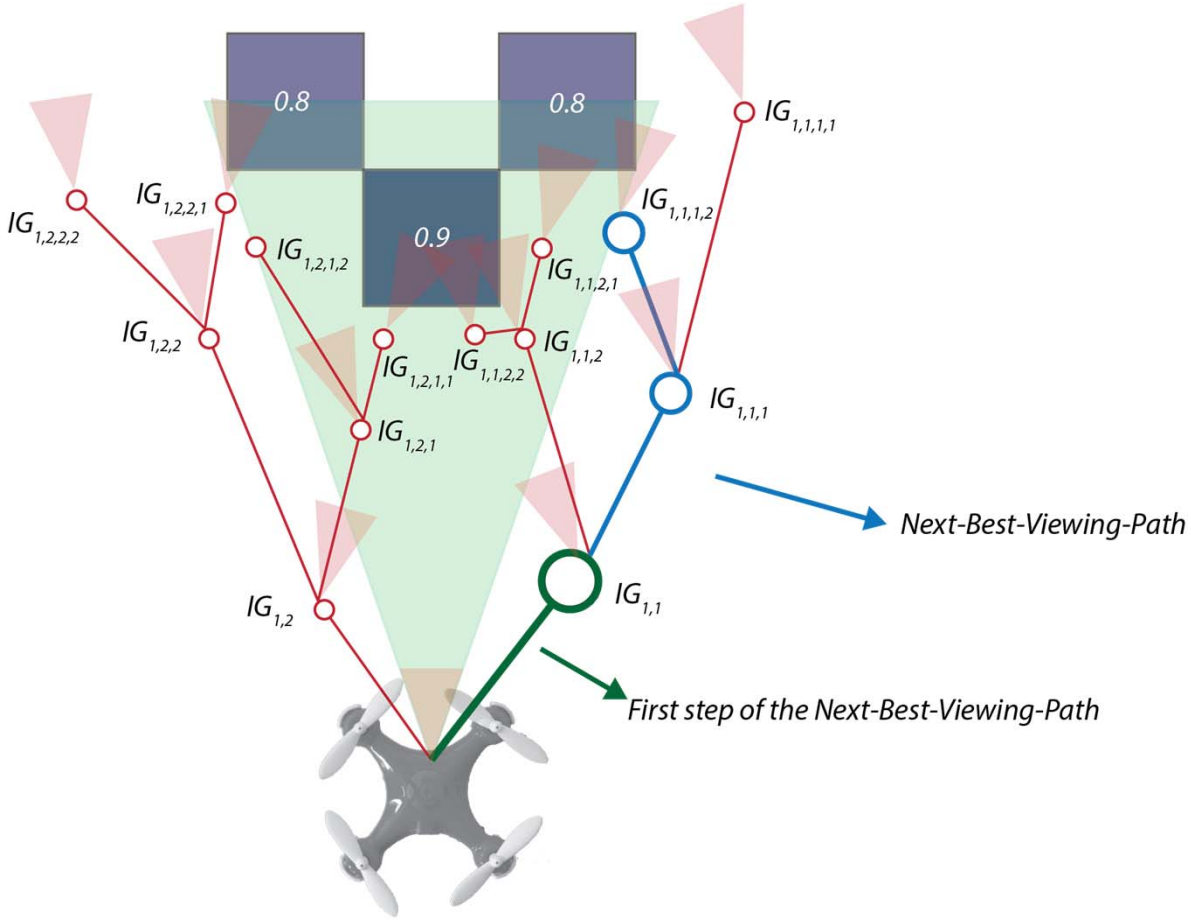


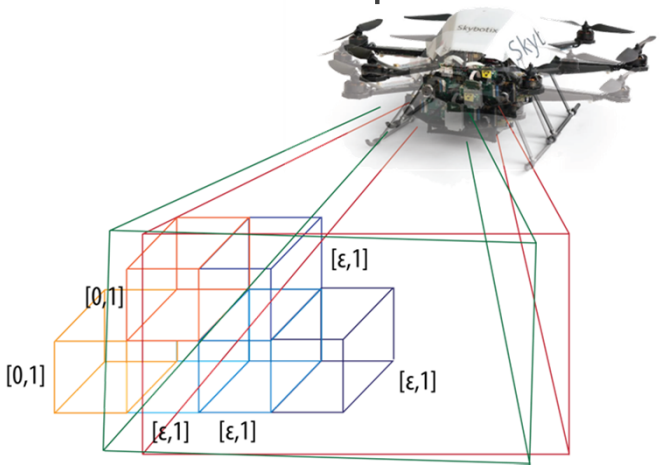
https://www.youtube.com/watch?v=0qeDc2mWIfI

Flying Manipulation | tree cavity inspection

- **3DOF robot arm**

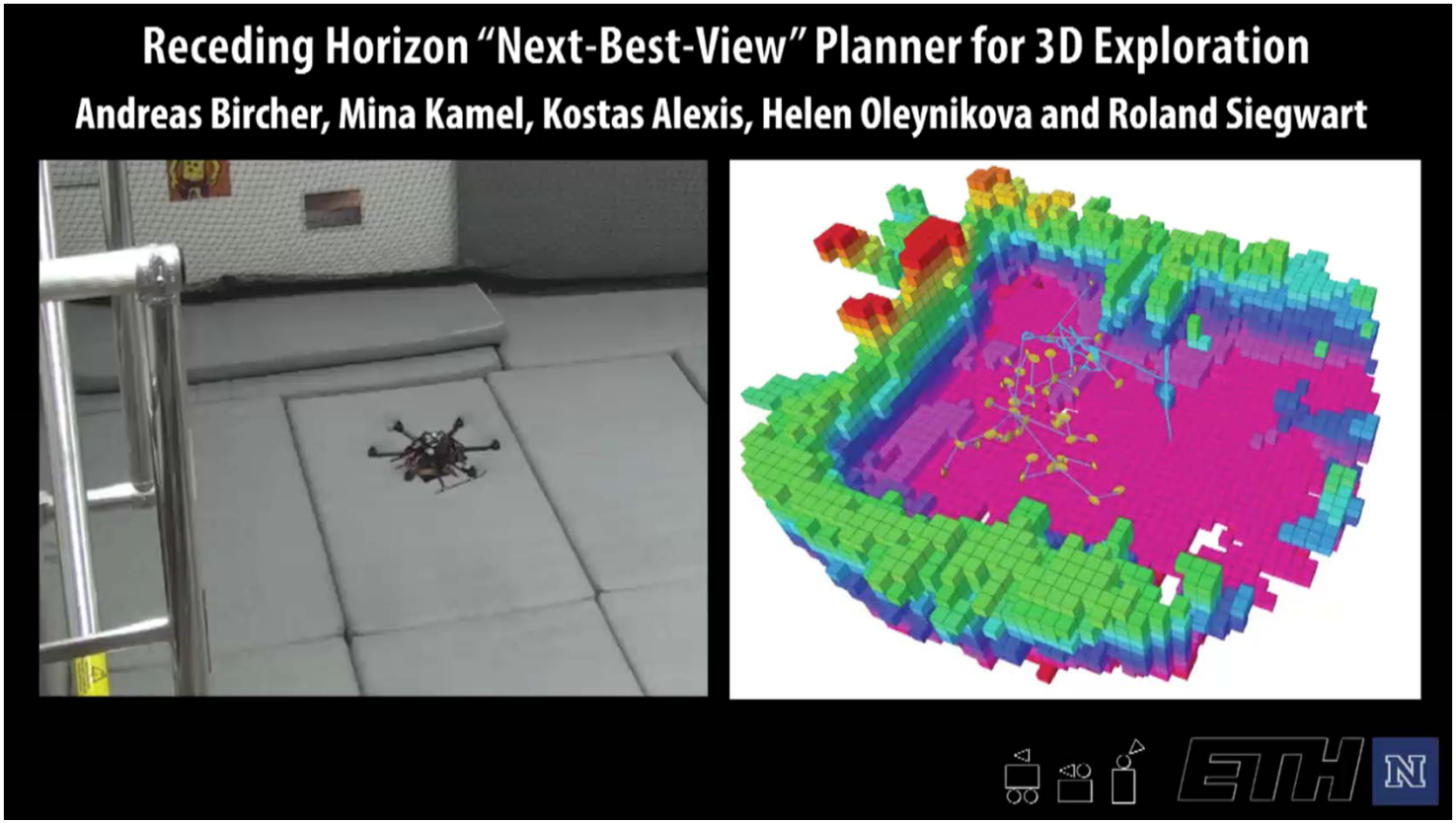
Autonomous Exploration Path-Planning | next best view planner





- On the current octomap knowledge expand an RRT with depth N_{NBVP}.
- Compute the Additive Information Gain of all possible paths of depth N_{NBVP}.
- Select the Next-Best-Viewing-Path
- Execute only the first step
- Repeat with on the updated octomap

Autonomous Exploration Path-Planning | next best view planner



Collaborative Visual-Inertial Navigation

in collaboration with

Prof. Marco Hutter

https://www.youtube.com/watch?v=9PprNdlKRaw

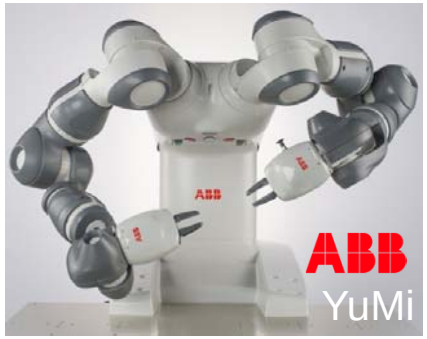
Opportunities / Markets

- Industrial transportation
- Cleaning
- Medical robotics
- Entertainment / edutainment

- Logistics
- Autonomous Cars

- Industrial inspection
- Surveillance and rescue
- Construction and mining
- Agriculture

- Health and elderly care
- Personal / services robots



The coffee servant
Nesspresso / Bluebotics, Switzerland

Zurich Area | a melting pot for robotics technology

Initiatives

(ASL)

roboticS Swiss National Centre of Competence in Research

National Centre of Competence in Research Digital Fabrication

ETH zürich

MAX-PLANCK-GESELLSCHAFT

Center for Learning Systems

Wyss Zurich TRANSLATIONAL CENTER

EU-Projects ASL

SHERPA

EUROPA 2

TRADR

AERO WORKS

European Robotics Challenges

Flourish

UP-Drive

Spin-offs (*ASL)

PIX4D simply powerful

senseFly

VERITY studios

GoPro Skybotix *

wingtra *

force dimension

aeon scientific

YouRehab inspire motivate achieve

noonee because its wearable

FEMTO TOOLS

MagnebotiX

Dacuda Scanning redefined.

Ophthorobotics AG

Fotokite

DISTRAN SWITZERLAND *

FLYABILITY

AEROTAIN *

BLUEBOTICS * Mobile Robots at Your Service

Rapyuta Robotics

Hocoma

Inspection Robotics *

Industrial Collaborations

Google

Project Tango

Disney Research, Zurich

ABB

menzi muck

TOTAL

HEXAGON

Leica Geosystems

BOSCH

NASA JPL

MOOG

intel

ASCENDING TECHNOLOGIES

ASL Team – Industrial Partners – Funding Agencies

- Current and former ASL Members