Flying Robots and Flying Cars

Heinrich H. Bülthoff

Biological Cybernetics Research at the
Max Planck Institute and Korea University

MAX-PLANCK-GESELLSCHAFT

Max-Planck-Institut
für biologische Kybernetik

KOREA UNIVERSITY 1905

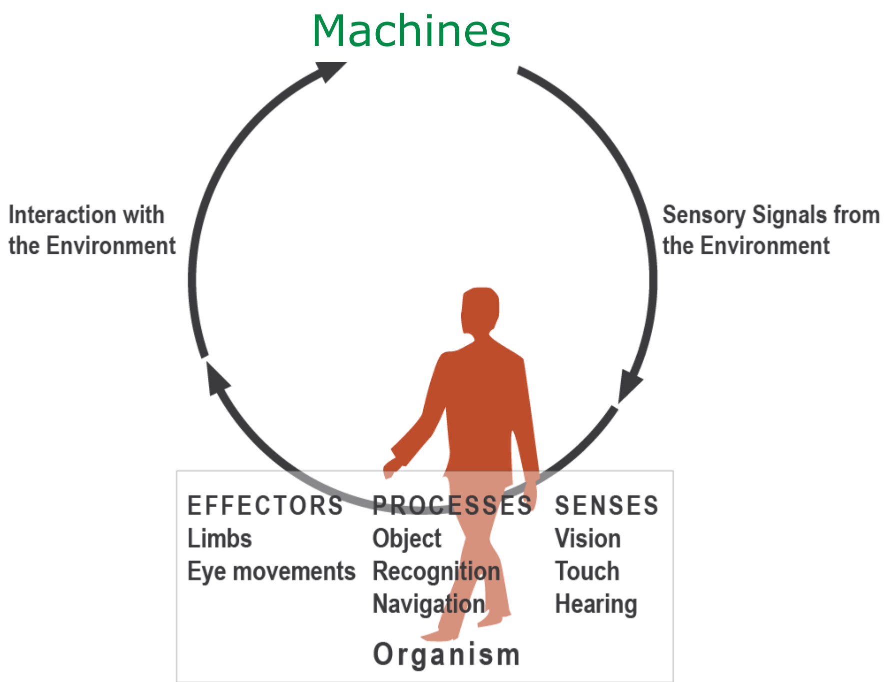
WCU

Dept. of Brain and Cognitive Engineering
Korea University

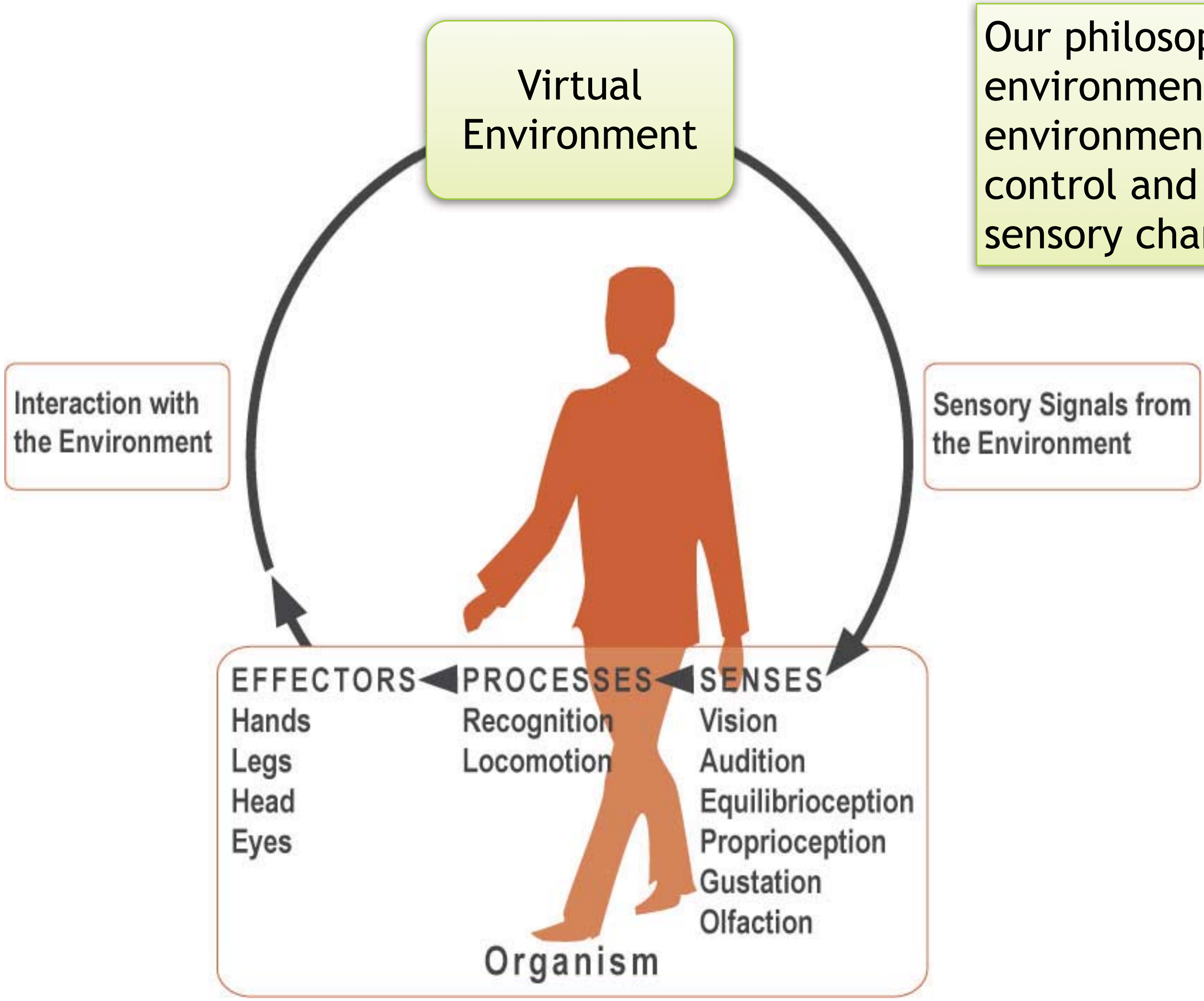
National Research Foundation of Korea R31-10008

My goal for today

- Present two examples for novel Man Machine Interaction
  - **Flying Robots --** Human Robot Interaction group at MPI Tübingen
  - **Flying Cars** -- European Project (myCopter)
- Both projects show new ways for effective and natural control
- Both integrate humans into the loop in order to build better Human-Machine-Interfaces



The Human: a complex cybernetic system



Our philosophy is to replace the environment with a virtual environment for better experimental control and to decouple the different sensory channels

Max Planck Institute for Biological Cybernetics
Department of Human Perception, Cognition and Action

Research Groups of the Department

Recognition and Categorization

We can easily and flexibly recognize objects at different levels depending on the task requirements. The goal of the group Recognition and Categorization (RECCAT) is to unravel the mechanisms underlying these two kinds of seemingly effortless tasks that we perform continuously.→ [more]

Perception & Action in Virtual Environment

In the Perception & Action in Virtual Environments research group, our aim is to investigate human behavior, perception and cognition using ecologically valid and immersive virtual environments. → [more]

Cybernetics Approach to Perception and Action

In the Cybernetics Approach to Perception and Action research group, our aim is to apply information theory, signal theory and advanced control system methods to understanding self-motion perception and action. → [more]

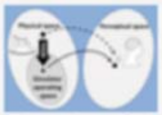
Human Robot Interaction

The aim of the Human-Robot Interaction group is to study novel ways to interface humans with robots, i.e., autonomous machines that are able to sense the environment, reason about it, and take actions to perform some tasks. → [more]

Cognitive Engineering

The Cognitive Engineering group develops applications based on Computer-Vision, Computer-Graphics and Machine-Learning in combination with methods that analyse Human cognitive processes.→ [more]

Motion Perception in Vehicle Simulation



The aim of the group is to establish a new approach to dynamic simulation. We focus on reproducing the perception of motion, rather than its merely physical characteristics, to increase the simulators performance and the impression of realism.→ [more]

Human Robot Interaction group

Bilateral shared control of Flying Robots

P. Robuffo Giordano

Antonio Franchi

H. Il Son





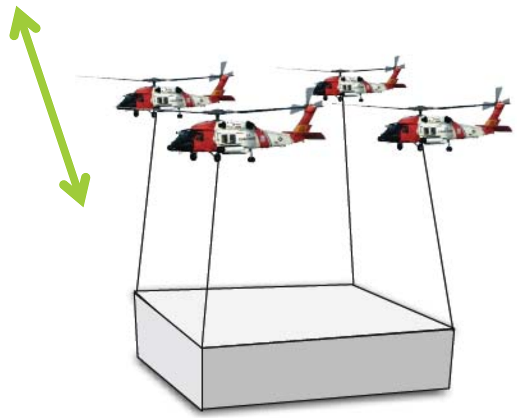



M. Cognetti, V. Grabe, J. Lächele, C. Masone, T. Nestmeyer, M. Riedel, M. Ryll, R. Spica

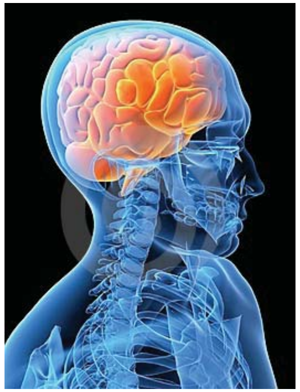
Flying Robots: Why

- Visual/Haptic control of a team of flying robots
- “flying eye” suitable for aerial exploration
- "flying hand" suitable for aerial manipulation

- The human commands the collective motion
- The robots must have their autonomy:
  - keep the formation
  - avoid obstacles
  - gather a map of the environment
  - pick and place operation
- The human receives a “suitable” feedback, e.g.:
  - inertia
  - forbidden directions (e.g., obstacles)
  - external disturbances (wind)

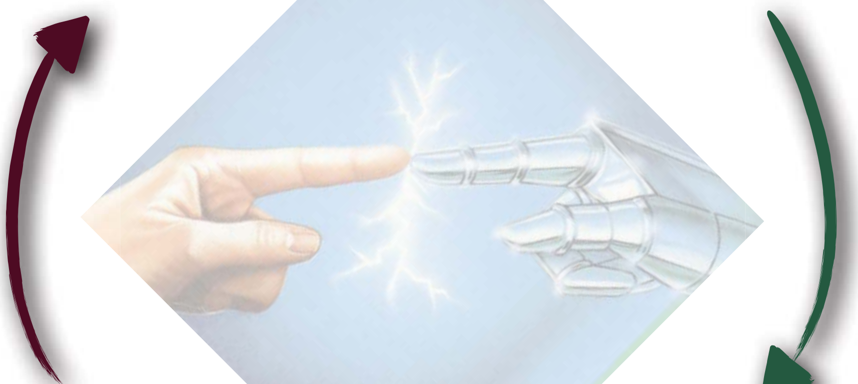


A mutually-beneficial interaction between Humans and Robots



Human assistance still mandatory:

- in highly **complicated** environments (dynamic, unpredictable)
- whenever **cognitive processes** are needed



Robotic assistance needed
to **extend** the human *perception* and *action* abilities

- higher **precision** and **speed**
- multi-scale **telepresence**
  from microscopy to planetary range

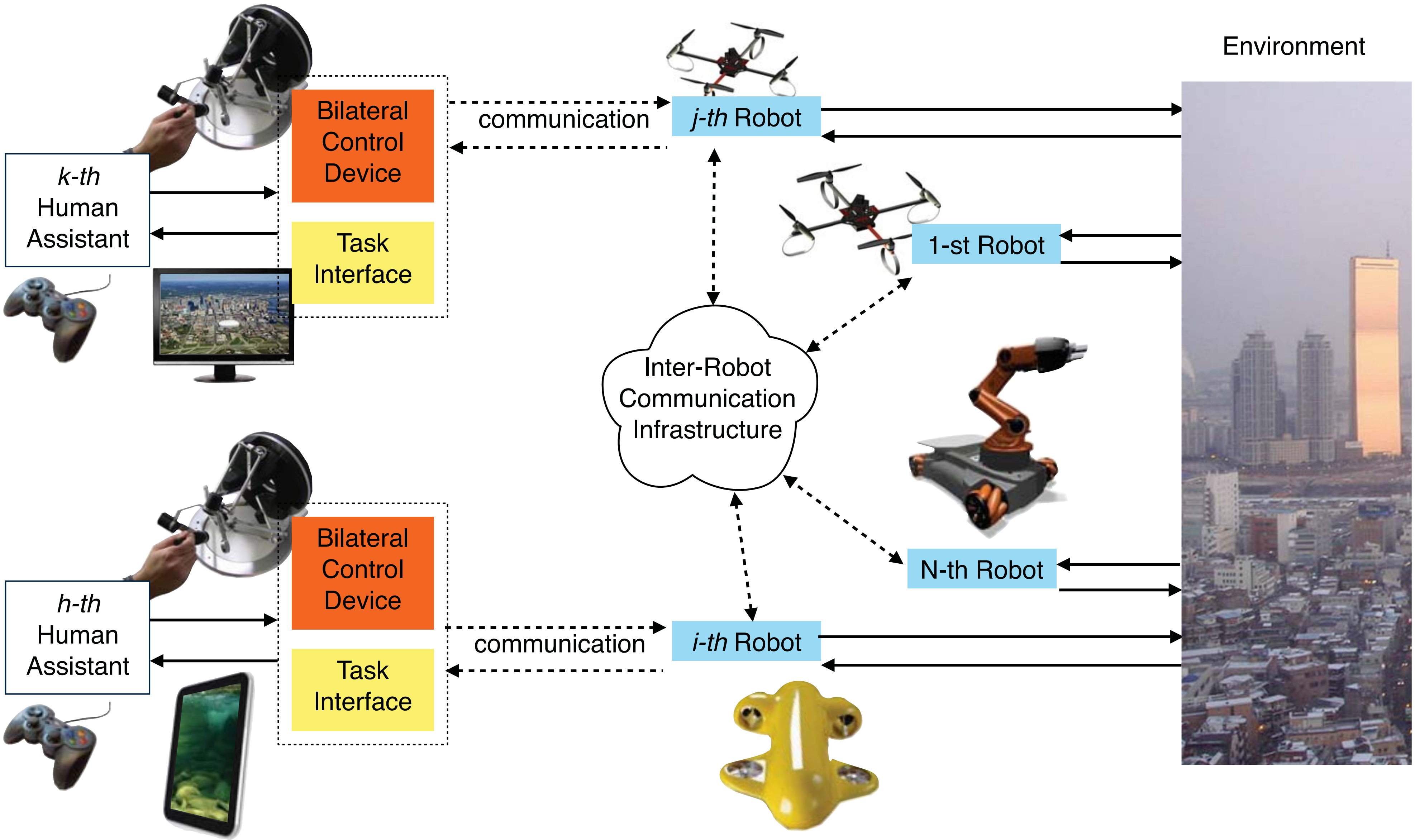
Multi-Robot Mobile Systems: Why

- **Multiple** Robots
- more effective and robust than a single complex one

- **Mobile** Robots
- more exploratory than fixed one

- Large number of applications
- exploration, mapping, surveillance, search and rescue
- transportation, cooperative manipulation
- sensor networks
- mobile infrastructures
- modular robotics
- nano-robot medical procedures

Bilateral Shared Control: Why



[Franchi,Secchi,Ryll,Bülthoff,RobuffoGiordano, *Bilateral Shared Control of Multiple Quadrotors: Balancing autonomy and human assistance with a group of UAVs*, IEEE Robotics & Automation Magazine, 2012]

Franchi, Secchi, Ryll, Bülthoff, Robuffo Giordano
Shared Control: Balancing autonomy and human assistance with a group of Quadrotor UAVs,
IEEE Robotics & Automation Magazine, Sep. 2012

By Antonio Franchi, Cristian Secchi, Markus Ryll, Heinrich H. Bülthoff, and Paolo Robuffo Giordano

Robustness and flexibility constitute the main advantages of multiple-robot systems with respect to single-robot ones as per the recent literature. The use of multiple unmanned aerial vehicles (UAVs) combines these benefits with the agility and pervasiveness of aerial platforms [1], [2]. The degree of autonomy of the multi-UAV system should be tuned according to the specificities of the situation under consideration. For regular missions, fully autonomous UAV systems are often appropriate, but, in general, the use of semiautonomous groups of UAVs, supervised or partially controlled by one or more human operators, is the only viable solution to deal with the complexity and unpredictability of real-world scenarios as in, e.g., the case of search and rescue missions or exploration of large/cluttered environments [3]. In addition, the human presence is also mandatory for taking the responsibility of critical decisions in high-risk situations [4].

In this article, we describe a unified framework that allows 1) letting the group of UAVs autonomously control its topology in a safe and stable manner and 2) suitable incorporation of some skilled human operators in the control loop. This way, the human's superior cognitive capabilities and precise manual skills can be exploited as a valid support for the typical autonomy of a group of UAVs. In fact, drawing

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Shared Control

Balancing Autonomy and Human Assistance with a Group of Quadrotor UAVs

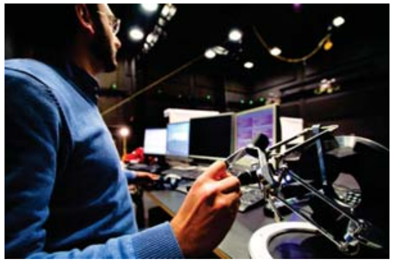
Digital Object Identifier 10.1109/MRA.2012.2205625
Date of publication: 28 August 2012

First Goal: Haptic Tele-Navigation

Navigation: the basis for any other (more complex) robotic task (e.g., exploration, mapping, transport, pick and place)

Human (operator) role:

- Gives **high-level** motion **commands** (e.g., move one leader, move the centroid, change the formation)



- Elaborates information recorded online by the UAVs
  - **visual feedback**
  - **haptic (force) feedback**, i.e., quantitative measurements conveyed by a force

Group of Robots (slave) role:

- Implements the high-level motion commands

- Records **environmental measurements** to be displayed to the operator

plus, **autonomously:**

- Avoid **obstacles**
- Avoid inter-robot **collisions**

Main Steps to Achieve Stable Haptic Tele-navigation

build a
Hardware/Software Platform

design and implement a
Stable and Tunable Aggregation Control

incorporate in the design:
High-level Intervention

incorporate in the design:
Haptic/Visual Telepresence

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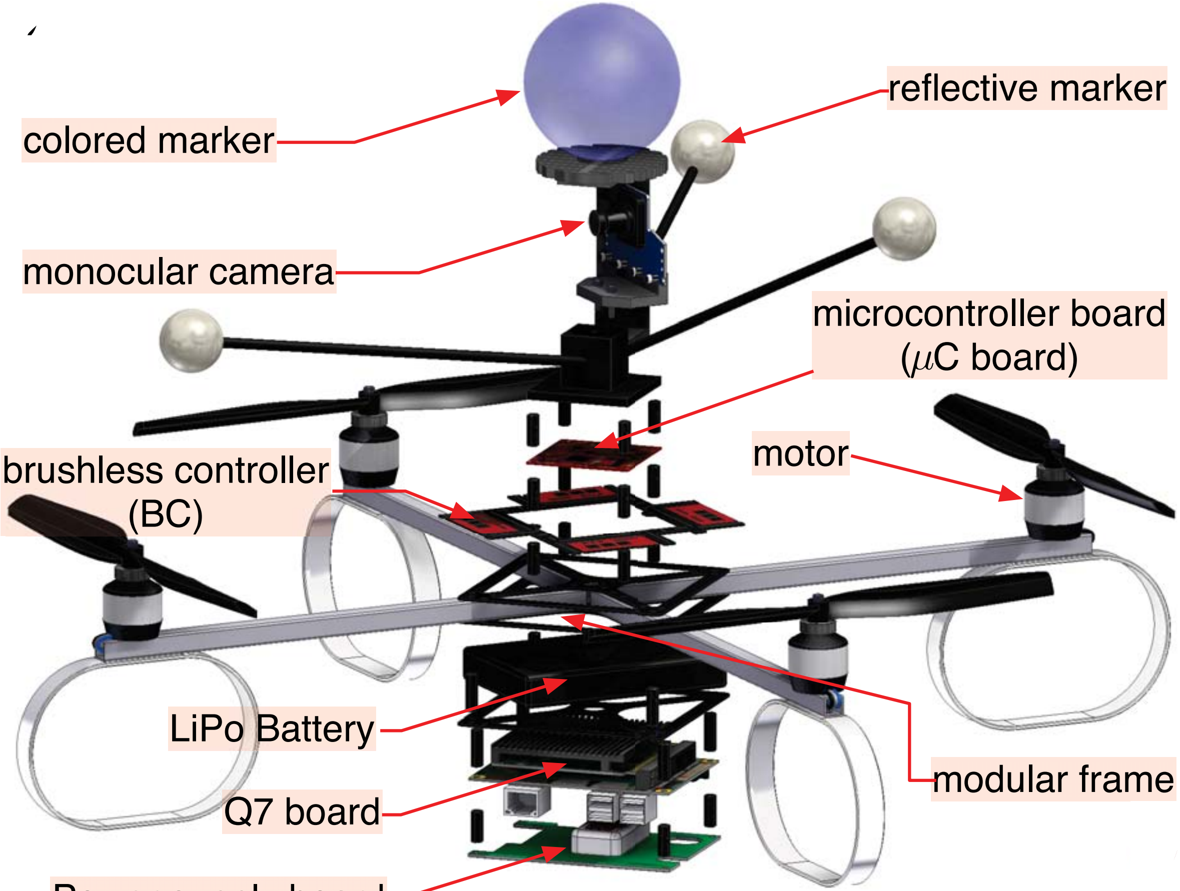
Hardware/Software Platform

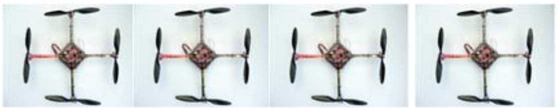
Haptic interfaces

Omega 6 and 3 (3+3-DOF)

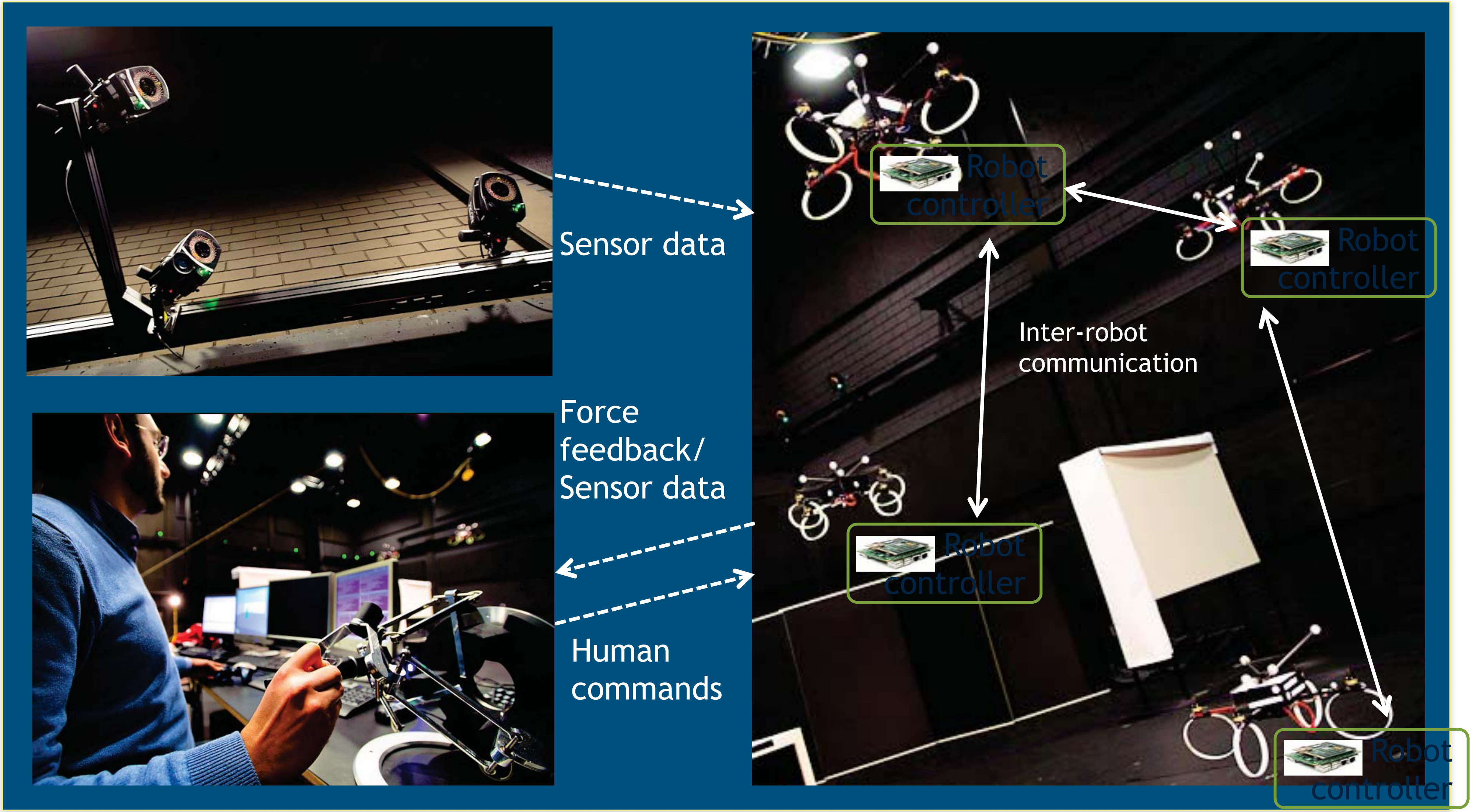
- Worksp: 160x110x120 mm
- Maximum force: 12.0 N
- Local force loop: 3 kHz

Custom **quadrotor** platform





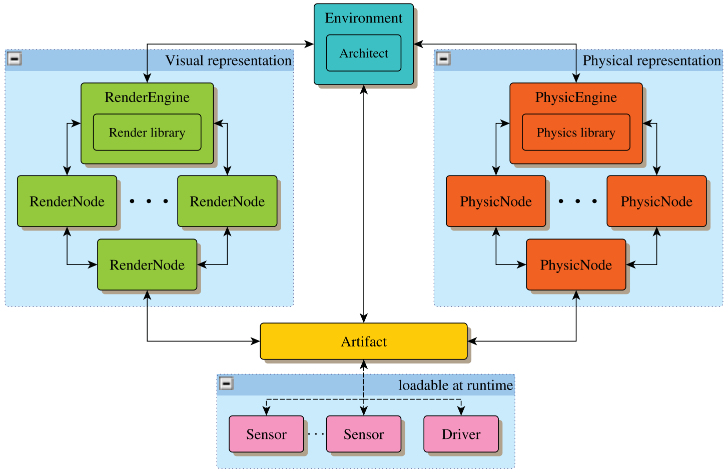
Hardware/Software Platform

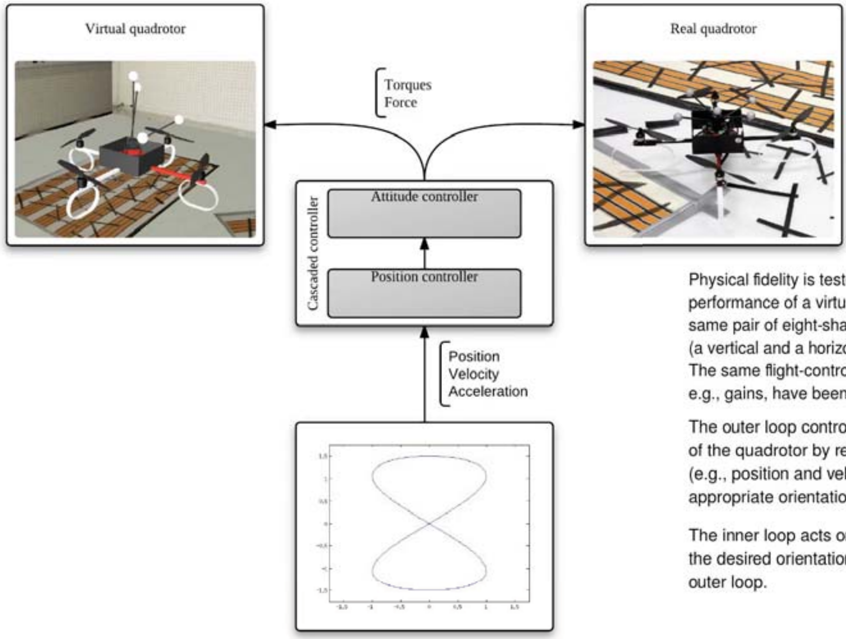


Johannes Lächele

Hardware/Software Platform

Physics (Engine) based Software Simulator





Physical fidelity is tested by comparing the tracking performance of a virtual and real quadrotor flying the same pair of eight-shaped trajectories (a vertical and a horizontal one)
The same flight-controller code and parameters, e.g., gains, have been used in the virtual and real case.

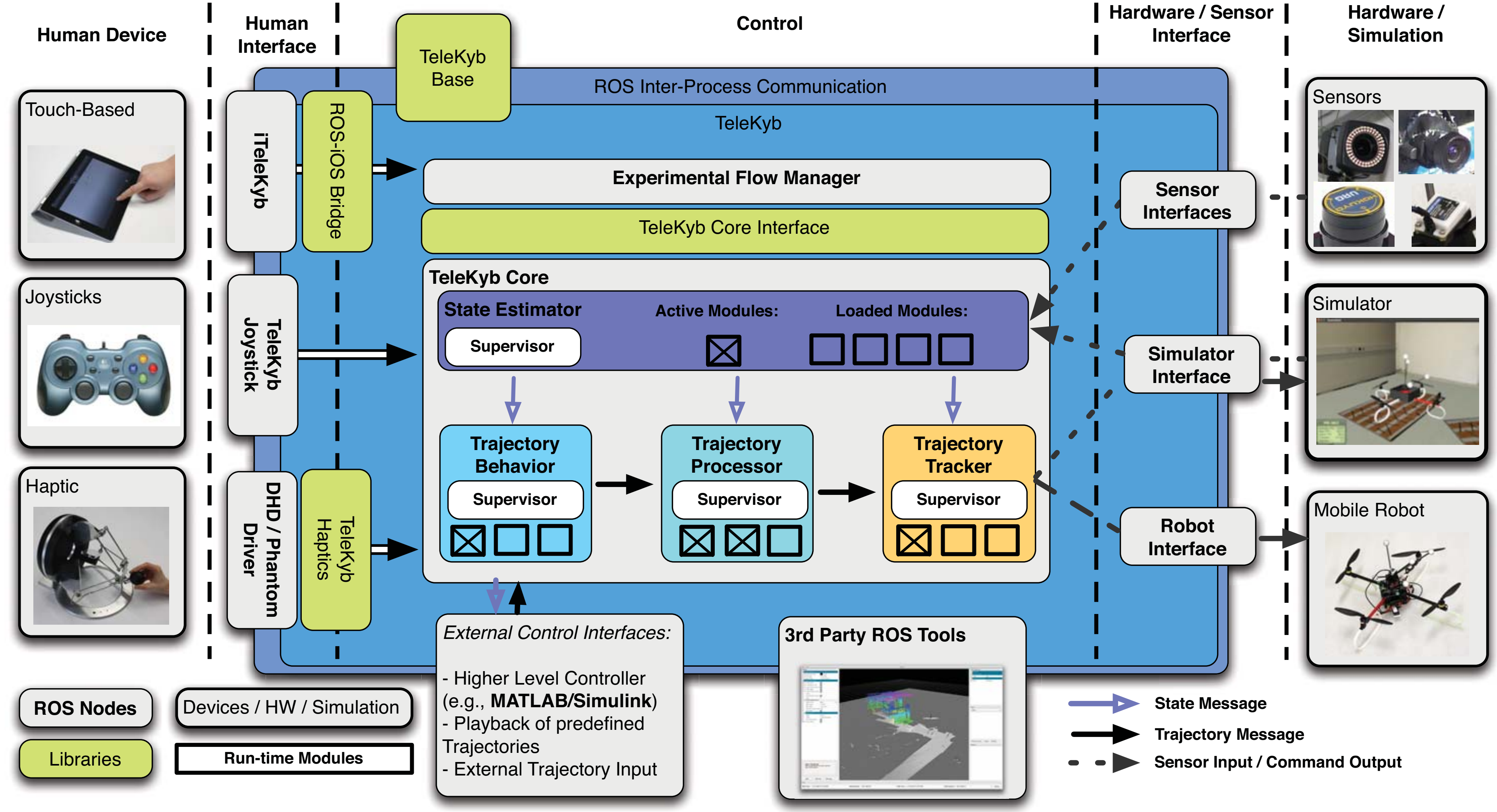
The outer loop controls the position and orientation of the quadrotor by reading the robot state (e.g., position and velocity) and providing the appropriate orientation and thrust to the inner loop.

The inner loop acts on the propeller speeds to achieve the desired orientation and thrust provided by the outer loop.

[Lächele et al., SIMPAR 2012]

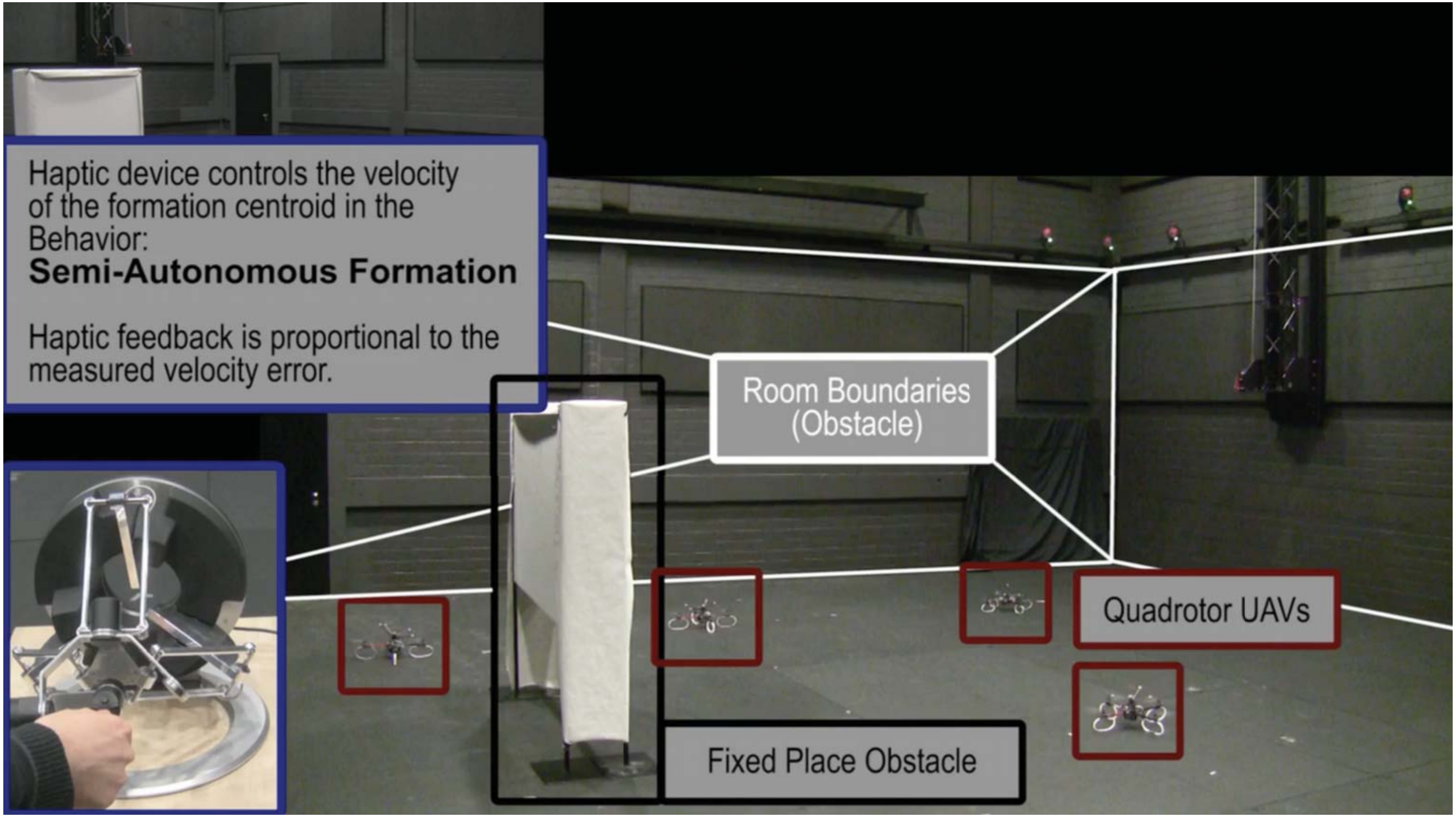
Martin Riedel

New Flexible Software Framework for Human/Multi-robot InterHaptivity

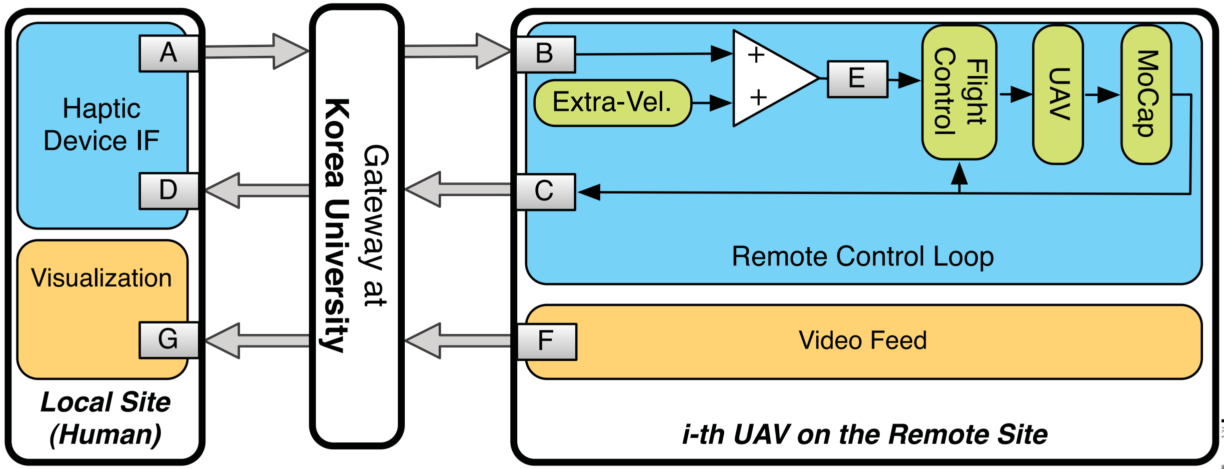


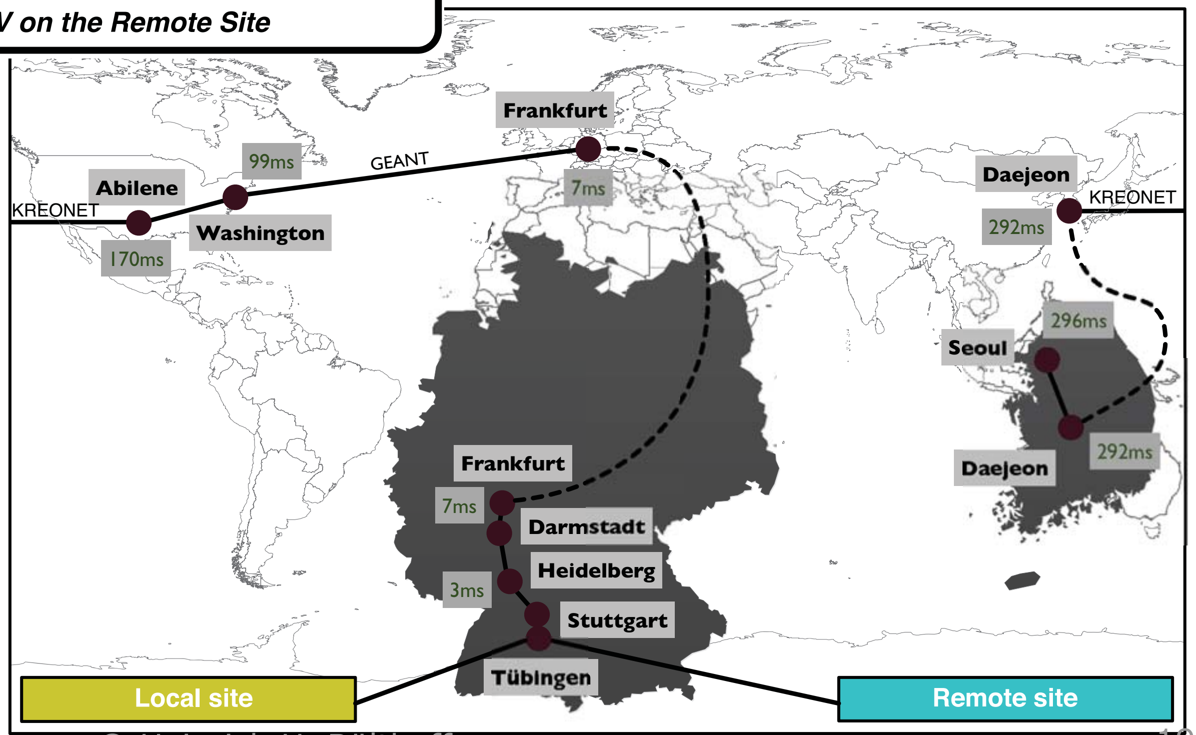
[Riedel&Al, *subm. to* ICRA 2013]

New Flexible Software Framework for Human/Multi-robot InterHaptivity



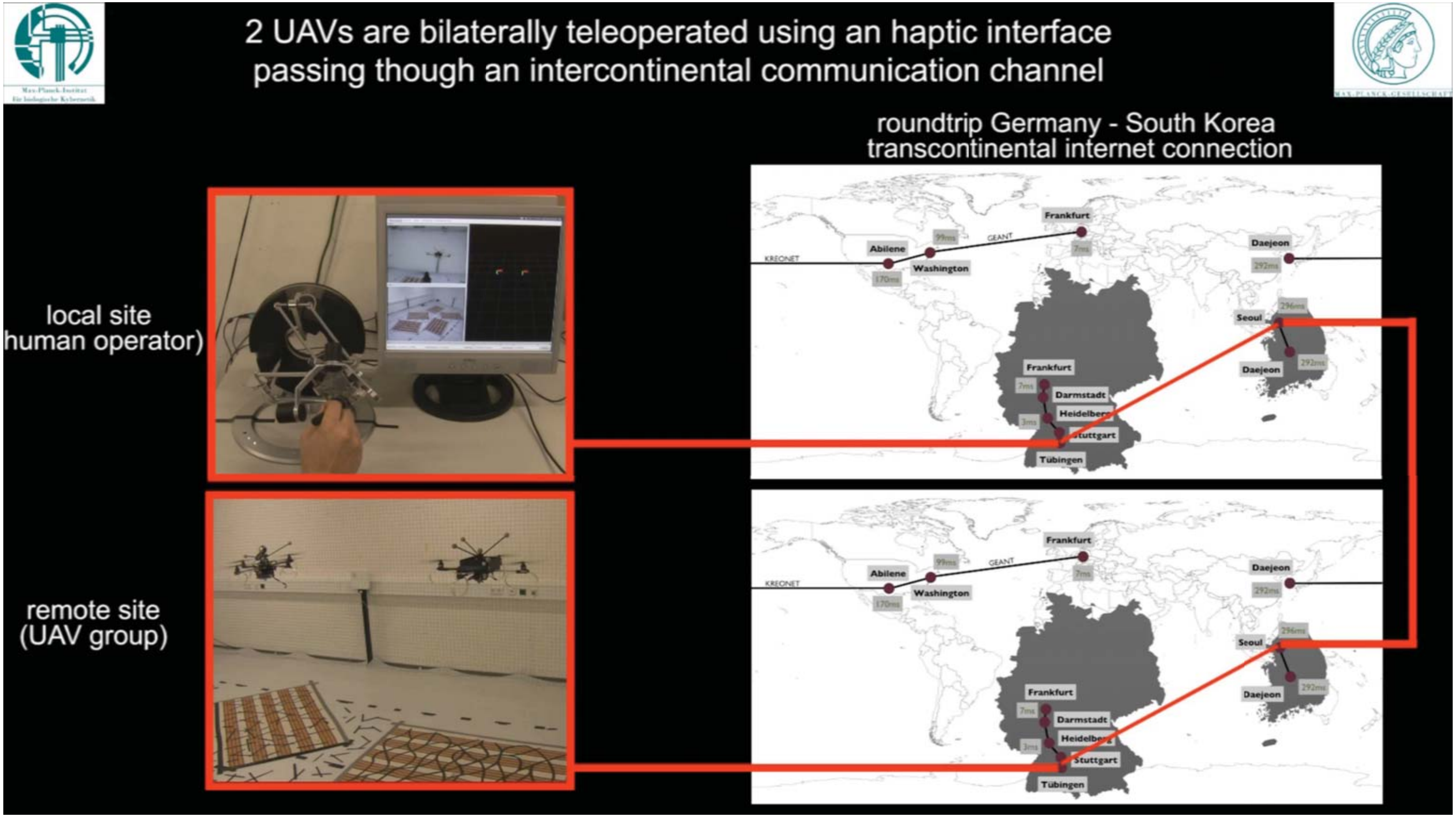
Intercontinental Haptic Tele-navigation





[Riedel et al., IAS 2012]

Intercontinental Haptic Tele-navigation



Main Steps to Achieve Stable Haptic Tele-navigation

build a
Hardware/Software Platform

design and implement a
Stable and Tunable Aggregation Control

incorporate in the design:
High-level Intervention

incorporate in the design:
Haptic/Visual Telepresence

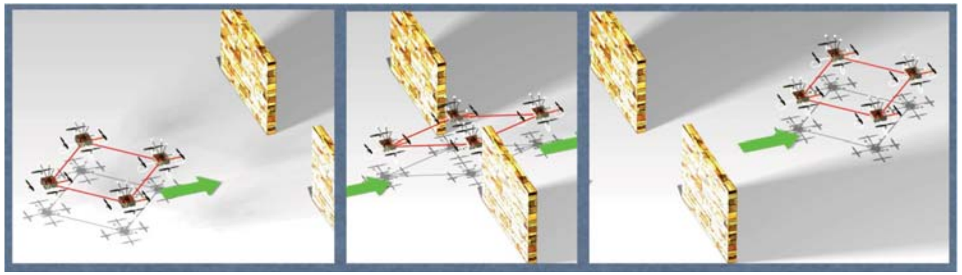
Control of the Group Topology

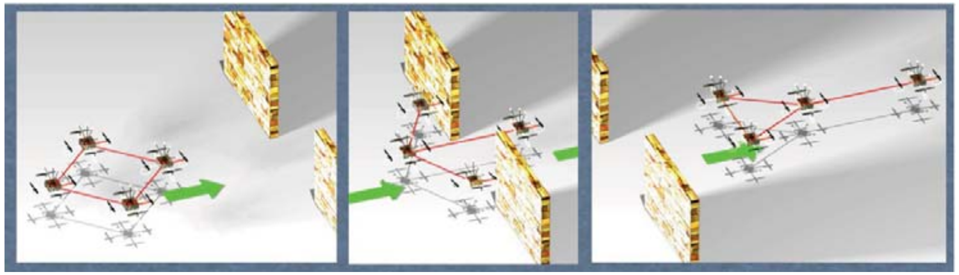
Flexibility:

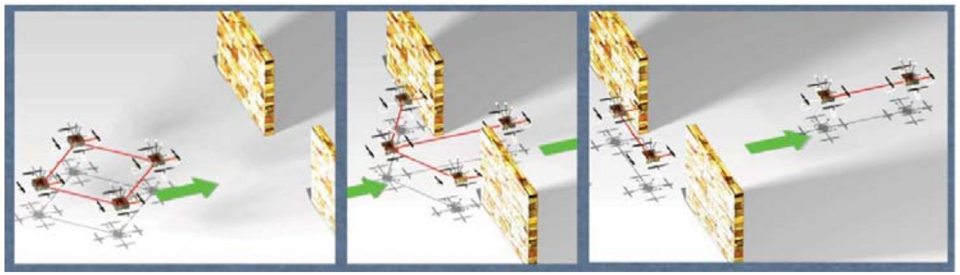
Topology:

- **Constant**
- Some **Property is preserved** (e.g., connectivity, rigidity, ...)
- **Unconstrained**

Examples:

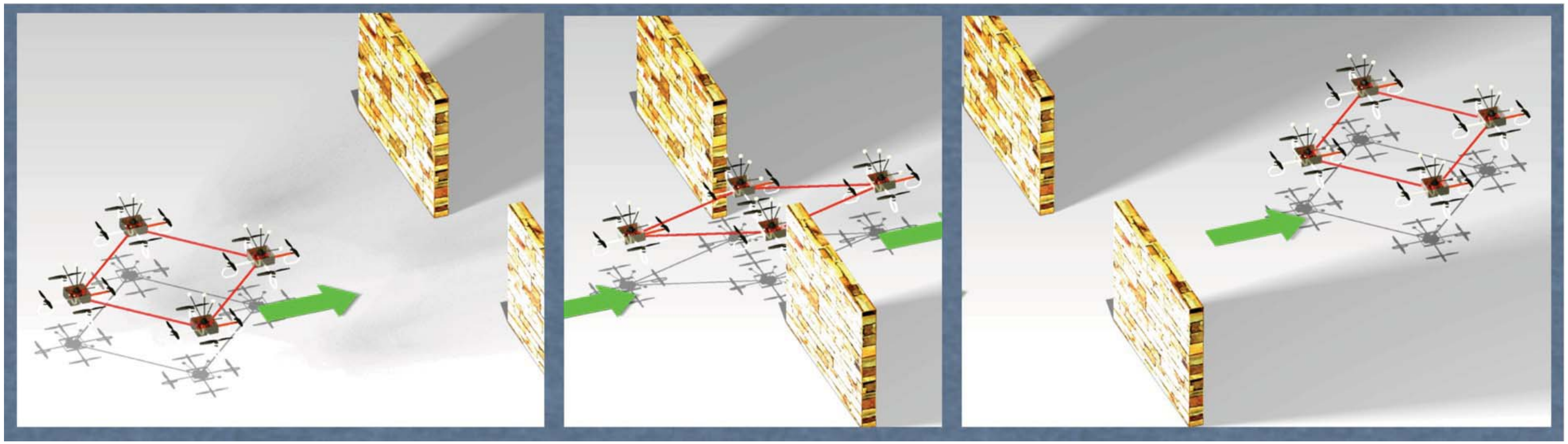






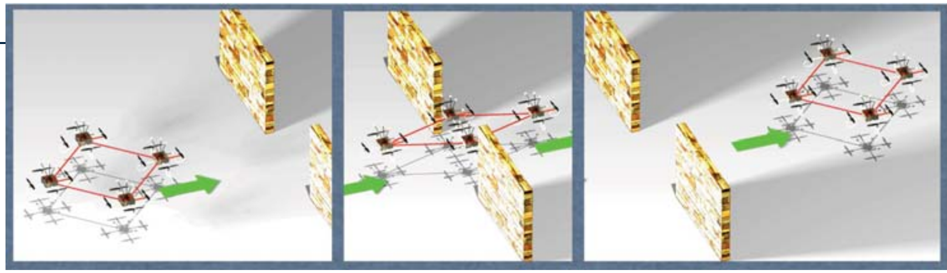
Constant Topology

- **local interactions** among robots
- **a priori fixed** geometric formation
- the formation undergoes elastic and **reversible transformations**
- elasticity: **crystal-like behavior** (rigid) to a **sponge-like** one (soft)



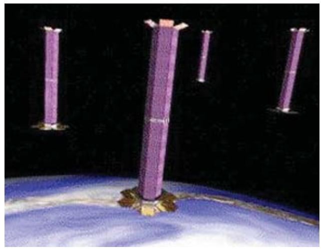
Constant Topology: Objectives and Measures

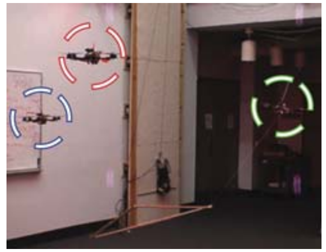
In the constant topology case a **desired shape** is given and must be **maintained**



Possible uses:

- taking precise **measurements**
- achieving **optimal communication**
- transportation





A shape is typically **placement-invariant** and is defined by **constraints**

Inter-distances

- *rotational invariant*
  - time-of-flight sensors, radar sensors
  - stereo cameras

Relative-bearings

- *rotational and* ***scale*** *invariant*
  - monocular camera

Constant Topology: Objectives and Measures

Two main approaches:

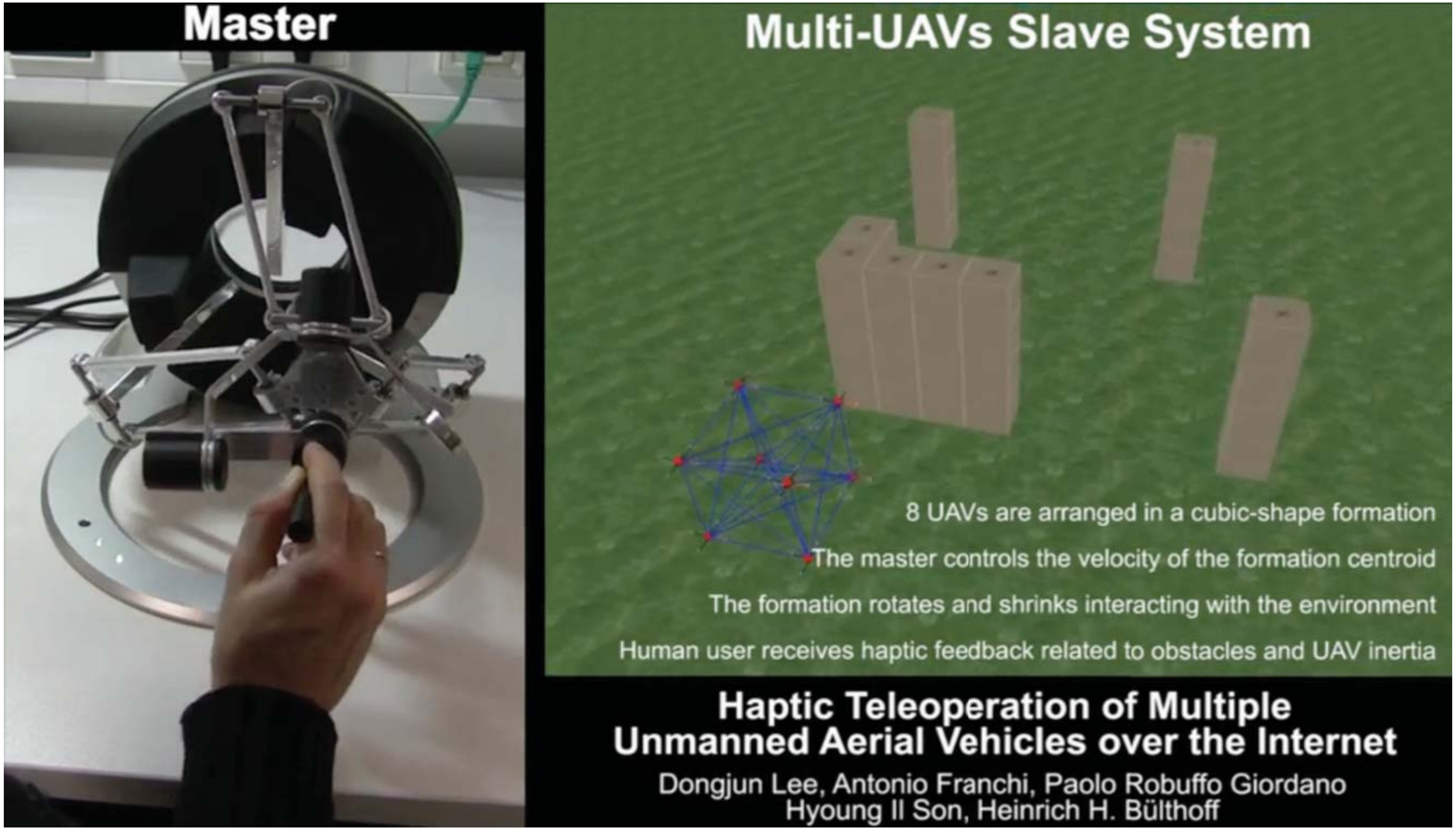
- measuring **positions**, and constraining **distances**

  [Lee et al., *subm. to IEEE/ASME Transaction on Mechatronics*, 2012]
  [Lee et al., ICRA 2011]

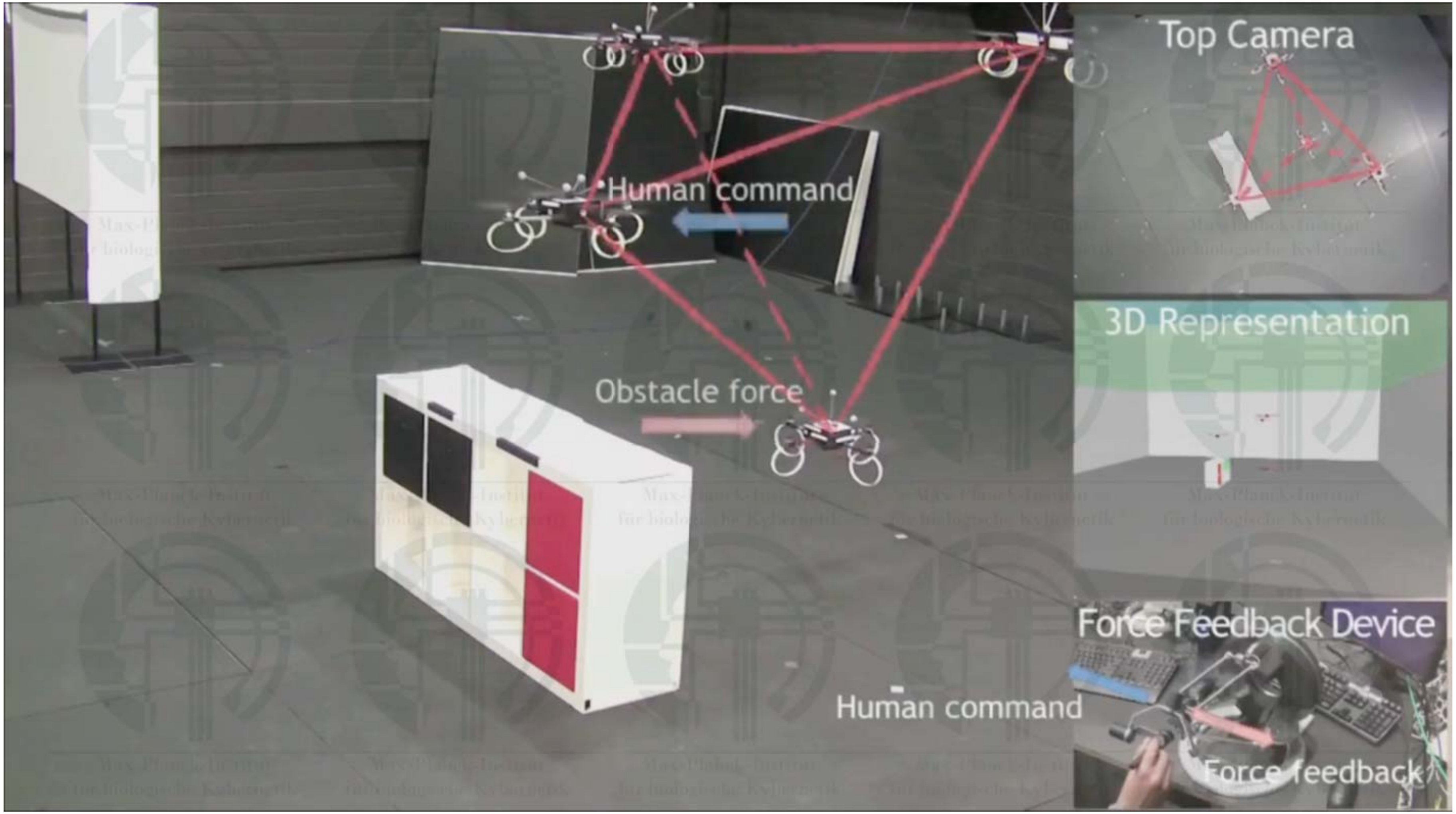
- measuring **bearings** (angles), and constraining **bearings**

  [Franchi et al., *International Journal of Robotics Research*, 2012]
  [Franchi et al., IROS 2011]

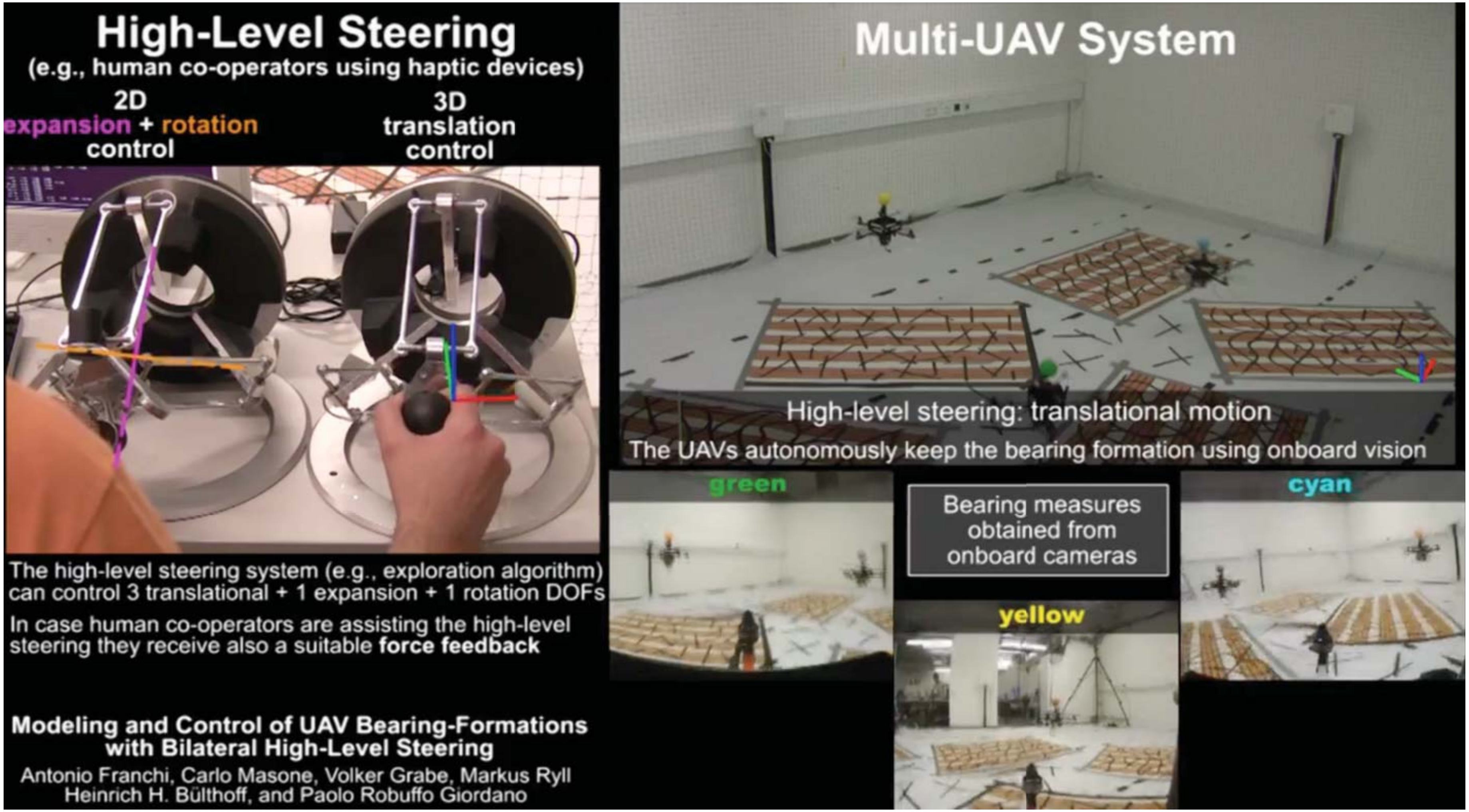
Measuring Positions and Constraining Distances



Measuring Positions and Constraining Distances

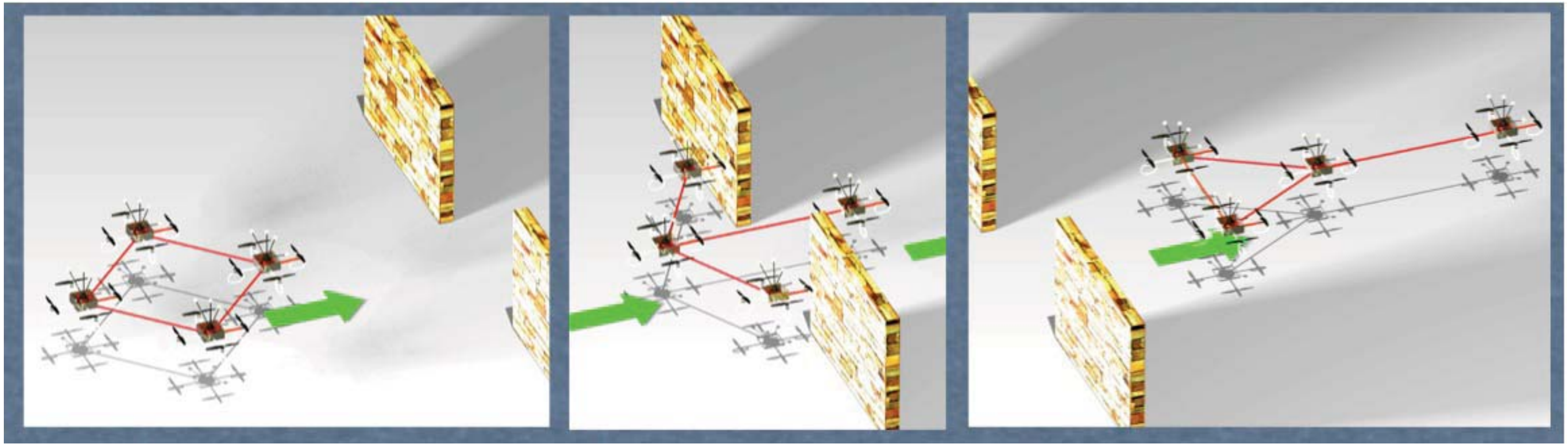


Measuring Bearings and Constraining Bearings



Non-constant Topology while Preserving Some General Property

- **essential-local interactions** among robots (spring-like)
- **undefined** and **variable** shapes (results of the inter-robot and environment interaction,
  amoeba-like behavior)
- links can be **broken** and **restored but some properties are always preserved**



Non-constant Topology while Preserving Some General Property

Two preserved properties:

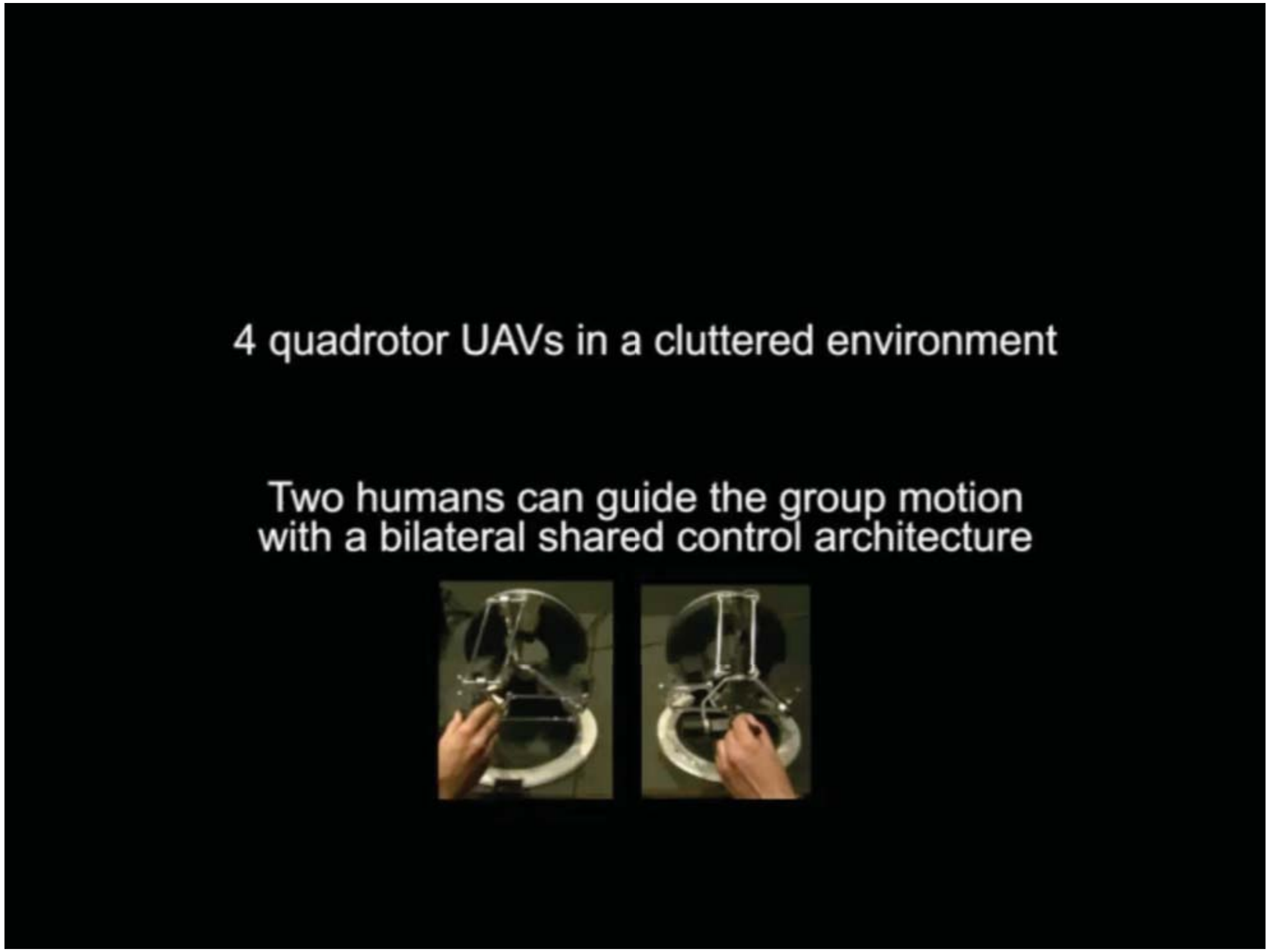
- communication **connectivity**

  [RobuffoGiordano et al., *International Journal of Robotics Research*, 2012]
  [RobuffoGiordano et al., RSS 2011]

- graph **rigidity**

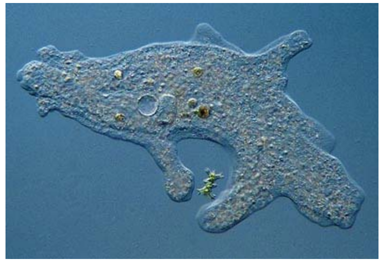
  [Zelazo et al., RSS 2012]
  [Zelazo et al., in preparation: *International Journal of Robotics Research*]

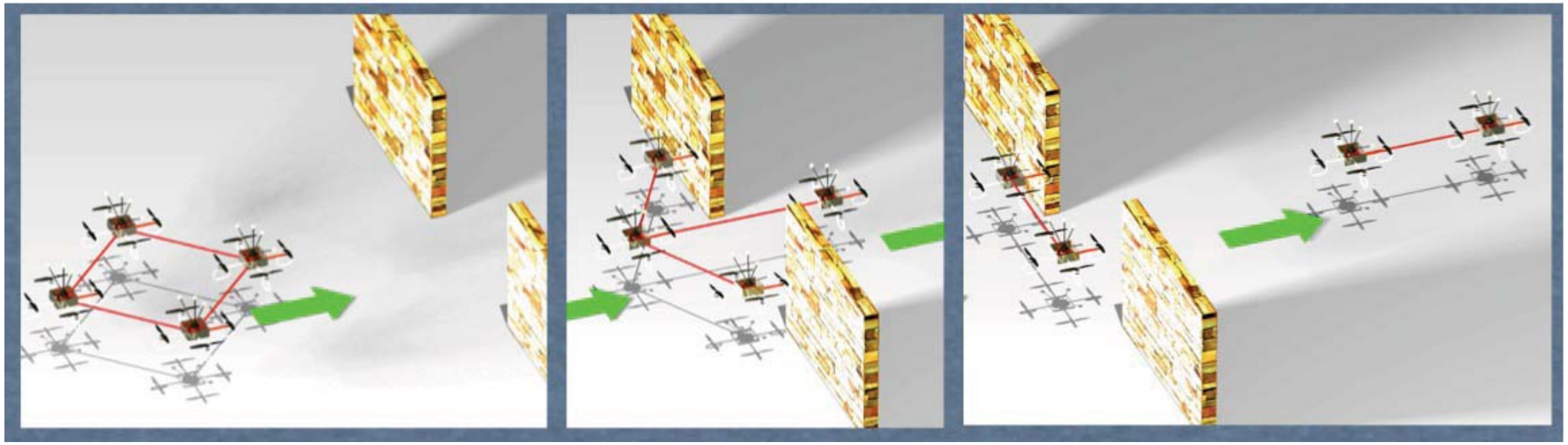
Connectivity-constrained Bilateral Shared Control



Totally Unconstrained Topology

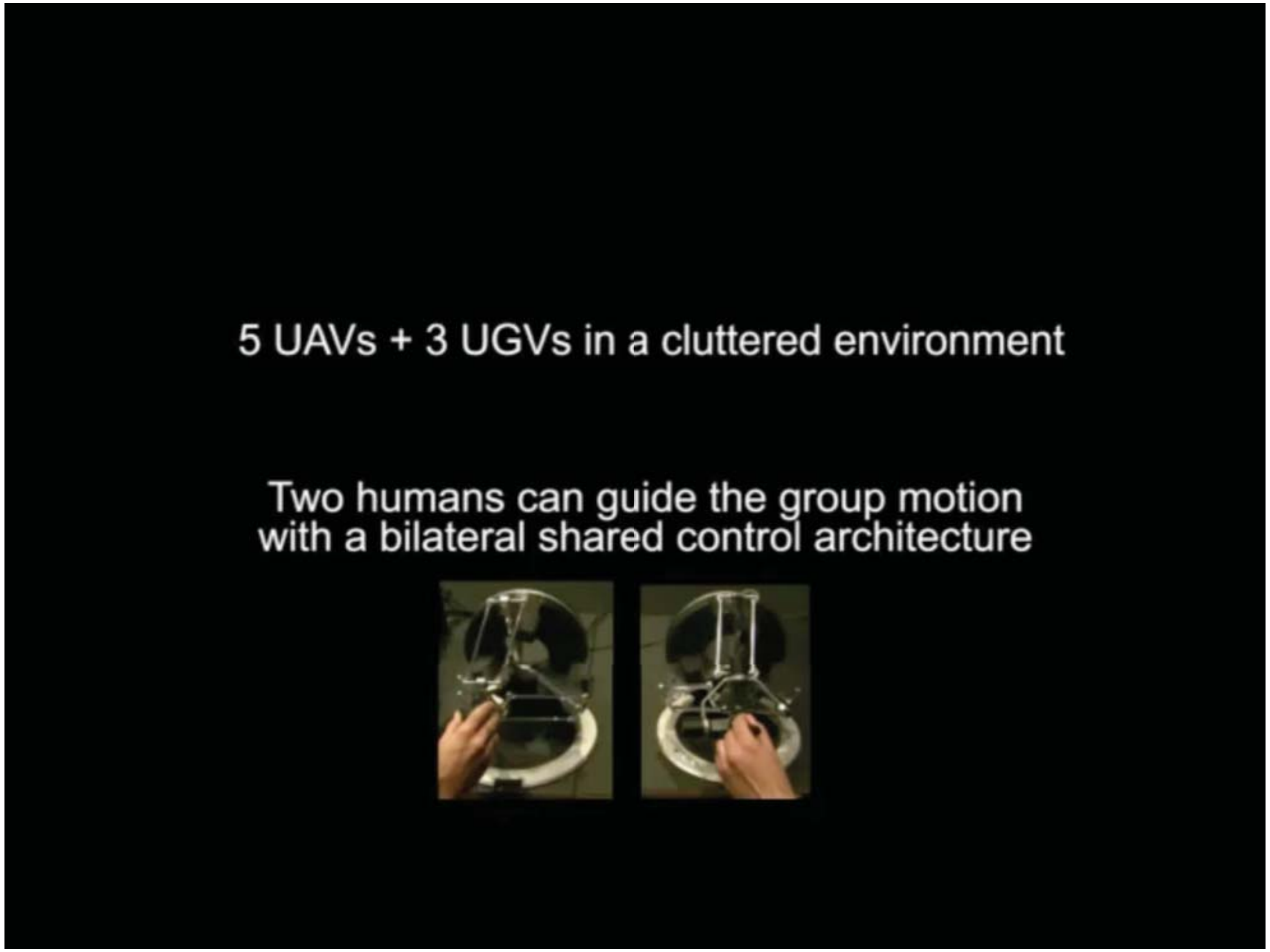
- **essential-local interactions** among robots (spring-like)
- **undefined** and **variable** shapes
  (results of the inter-robot and environment interaction, **amoeba**-like behavior)
- links can be **broken** and **restored**
- **challenge:** ensure a stable behavior despite the switching dynamics:
  - use of **passivity theory** and **port-hamiltonian** formalism





[Franchi et al., *IEEE Transaction on Robotics*, 2012]
[Franchi et al., ICRA 2011], [RobuffoGiordano et al., IROS 2011], [Secchi et al., ICRA 2012]

Totally Unconstrained Topology



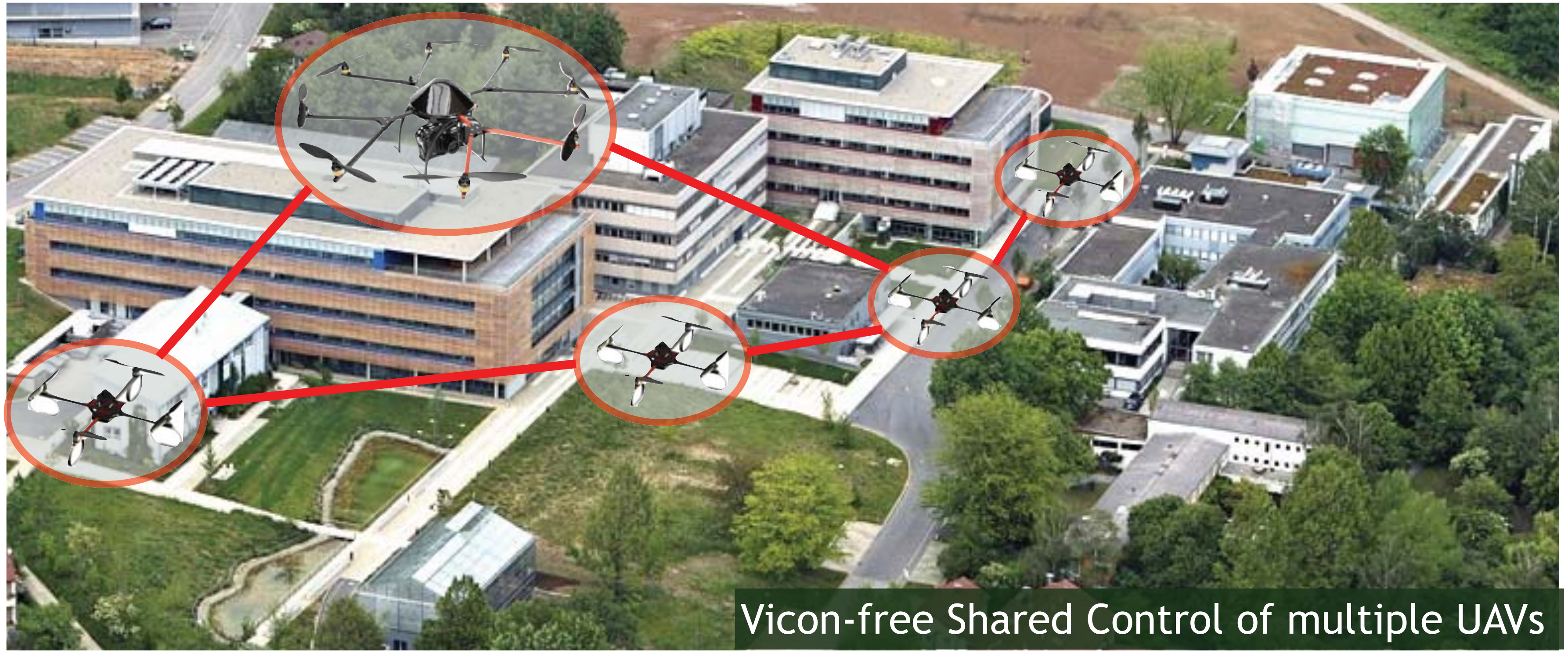
The Next Step: Beyond a Stable Haptic Tele-navigation

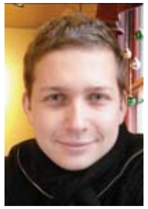
Autonomy from High-rate External Localization (Vicon)

Real world has **no high-rate** position/orientation **localization** available

Extend the presented algorithms (exploration, connectivity maintenance,...) taking into account **real world** constraints

- probabilistic sensor model
  - fit the range-visibility model
  - create a different model: modify algorithm
- probabilistic environmental model
  - position uncertainty
  - obstacle uncertainty



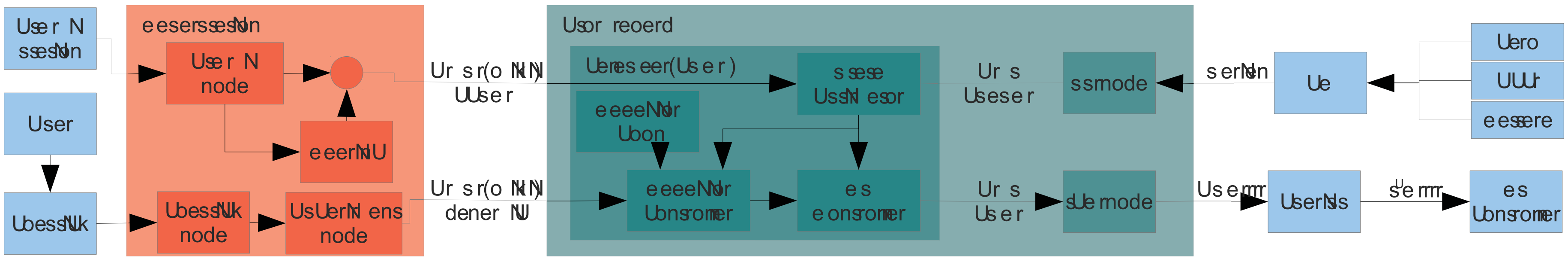
Autonomy from External Localization (Vicon)

Improved Hardware Platform

- EKF state estimation
- Automatic calibrations
- Onboard computation capabilities

Vision+IMU estimation

- velocity sensor

[Spica et al., *subm. to* ICRA 2013] [Grabe et al., ICRA 2012, IROS 2012, *subm. to* ICRA 2013]

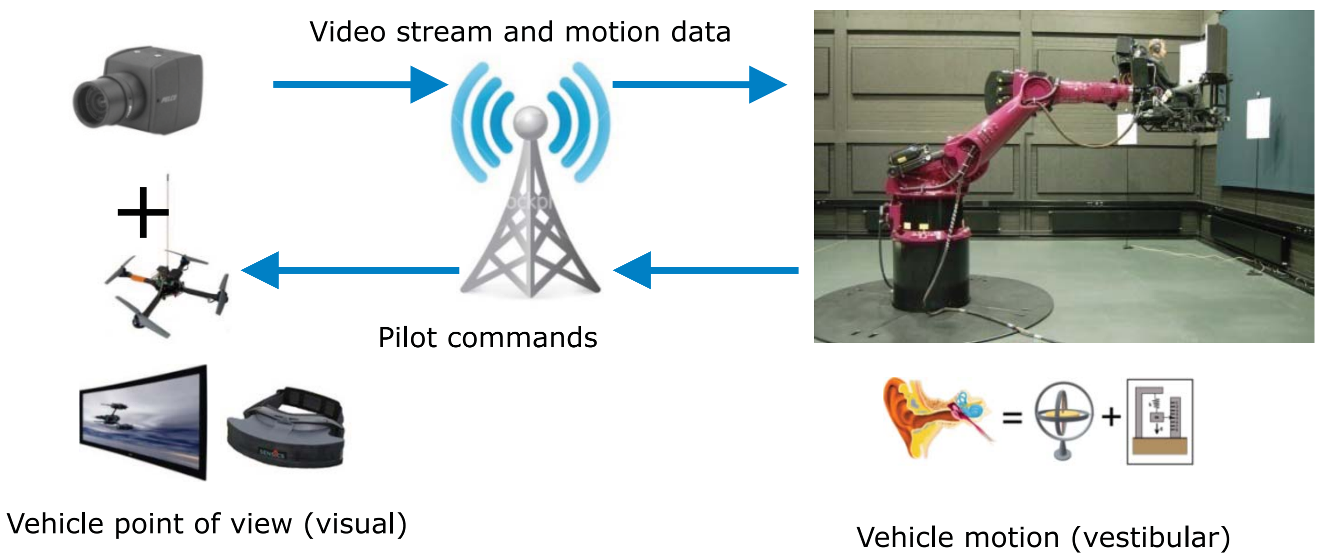
Autonomy with human-in-the-loop

Exploring additional **sensor/interaction modalities**

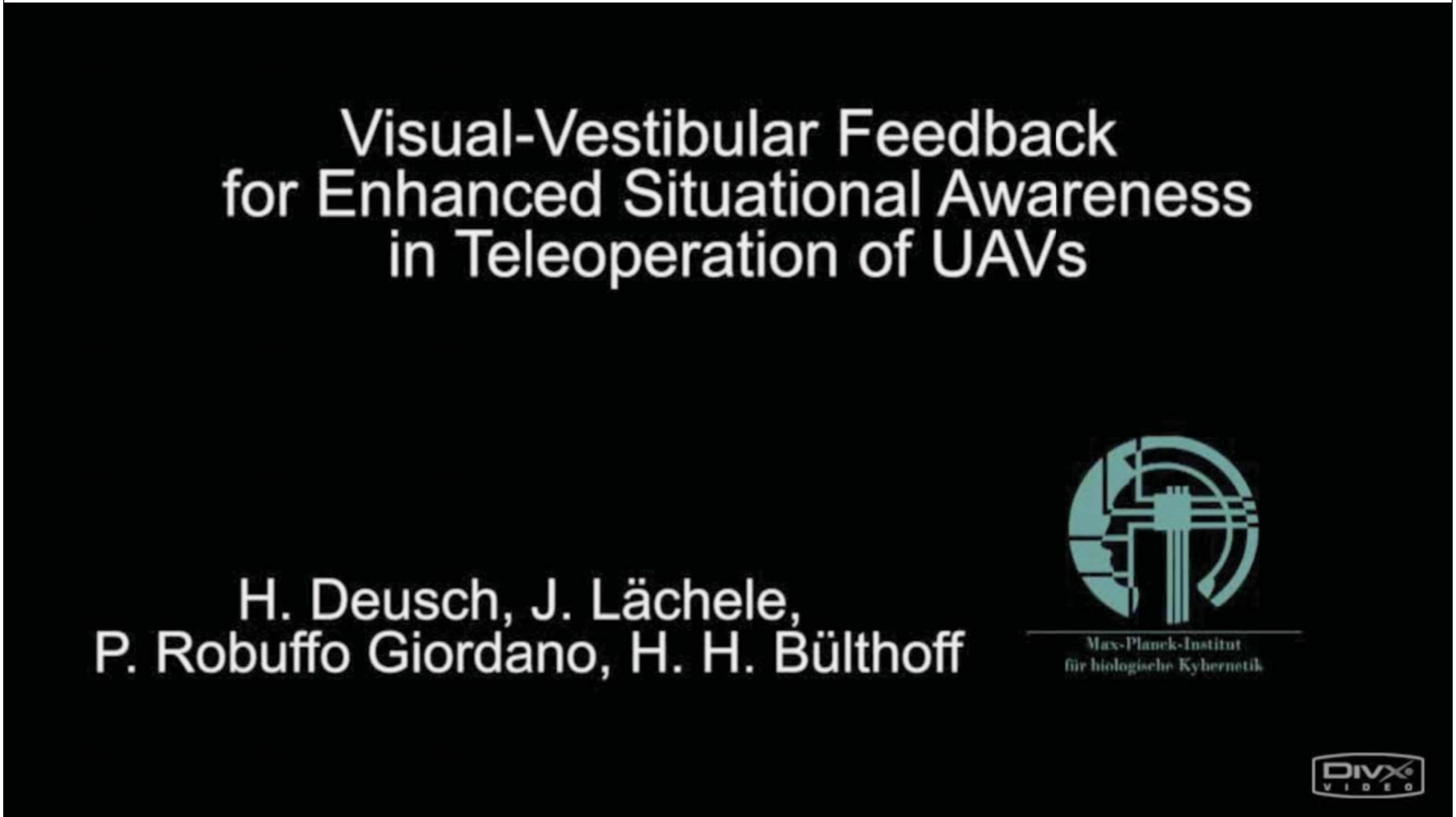
- Vestibular
- Tactile
- Stereo vision
- Panoramic vision
- ...

Remote control of Unmanned Aerial Vehicles (UAVs)

- Add vestibular feedback to enhance situational awareness
  - Scenario: remote teleoperation of a flying vehicle (in our case a quadcopter)
  - Hypothesis: vestibular feedback improves situational awareness for the pilot (and thus facilitates task execution)



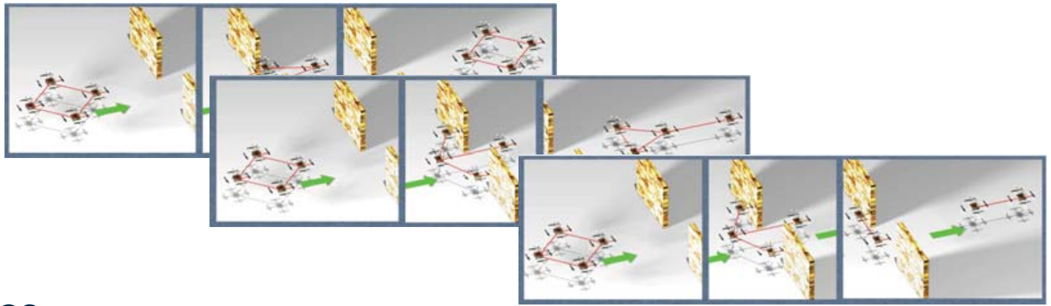
Teleoperation of Unmanned Aerial Vehicles
AHS 66th (2010)



Quick Summary

- Formal framework for establishing a bilateral shared control for interacting with multiple mobile robots

- Fixed topology with deformation
- Property-preserving topology
- Unconstrained Topology

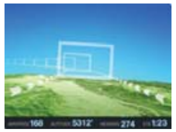


- Global/Local intervention and Telepresence
- Beyond Haptic Tele-Navigation
    - **a full multi-sensory experience of flying**
    - **like a fly**
    - using all the tools (toys) in our Cyberneum

From Flying Robots to Flying Cars

- **What information is needed for a human to pilot a vehicle, either directly or remotely to:**
  - drive a car, fly an airplane, stabilize a helicopter, etc.
- **How to present the information in order to:**
  - increase situational awareness (esp. in remote control tasks)
  - facilitate task execution
  - develop better/faster training procedures

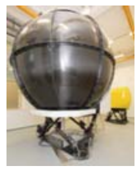
- **Multi-sensory Interfaces**
  - visual cues: tunnel-in-the-sky, glass cockpit



  - haptic cues: force-feedback devices

  - tactile cues: tactile vests

  - vestibular (self-motion) cues



MAX-PLANCK-GESELLSCHAFT

What if we simply fly to work?

Max-Planck-Institut
für biologische Kybernetik

myCopter – Enabling Technologies for Personal Aerial Transportation Systems

Prof. Dr. Heinrich H. Bülthoff
Max Planck Institute for Biological Cybernetics
Tübingen, Germany

mycopter

Project funded by the European Union under the
7th Framework Programme

http://www.mycopter.eu

The dream of flying cars is not new

- Many flying vehicles have been envisioned, but none made it to the market

ConVairAir, 1940s

Taylor Aerocar, 1950s

American Historical Society, 1945

Recent developments

- Technology exists to build aircraft for individual transport
  - Many concepts have already been developed
- Drawbacks of current designs
  - Not for everyone (needs a pilot license)
  - Could represent a compromised design

PAL-V

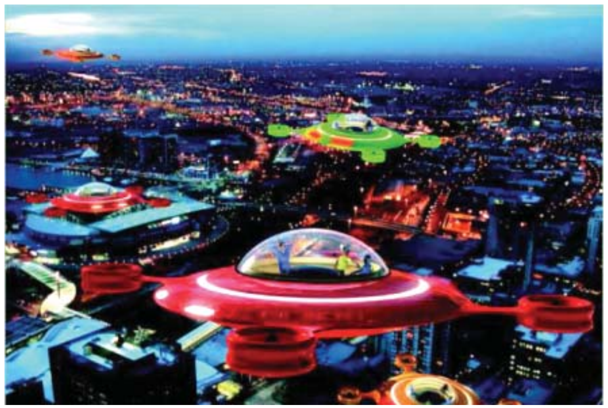
E-volo, Syntern GmbH

Transition® street-legal aircraft, Terrafugia

Many challenges ahead

- Our goal is not to design a specific Personal Aerial Vehicle (PAV)
  - "Designing the air vehicle is only a relative small part of overcoming the challenges… The other challenges remain…" [*EC, 2007*]

We want to address the challenges of building a Personal Aerial Transportation System (PATS)



[*EC, 2007*] European Commission,
Out of the box - Ideas about the future of air transport, 2007

Rationale for the project

- **Money:** ±*100 billion Euros* in the EU are lost due to congestion
  - 1% of the EU's GDP every year [EC, 2007]
- **Fuel:** *6.7 billion gallons* of petrol are wasted in traffic jams in USA
  - Each year, 20 times more gasoline than consumed by today's entire general aviation fleet. [Schrank, 2009]
- **Time:** In Brussels, drivers spend *50 hours* a year in road traffic jams.
  - Similar to London, Cologne and Amsterdam [EC, 2011]

My vision:

Use the third dimension!

[EC, 2008] "Green Paper - Towards a new culture of urban mobility," Sept. 2007, Commission of the European Countries, Brussels.

[Schrank, 2009] "2009 Urban Mobility Report," The Texas A&M University System, 2009

[EC, 2011] "Roadmap to a Single European Transport Area," 2011

Current transportation systems

Long-distance transportation

+ High-speed (planes / trains)
– Specific locations (airport / stations)
– expensive infrastructure (ATC, rails)

Short-distance transportation

+ Door-to-door travel (cars)
– Relatively slow (traffic jams)
– expensive infrastructure (roads, bridges, …)

Neuwieser, Flickr

Hoff1980, Wikipedia

Ian Britton, FreeFoto.com

Existing road traffic has big problems
maintenance costs, peak loads, traffic jams, land usage

Future transportation systems: EU-project myCopter

- Duration: Jan 2011 – Dec 2014
- Project cost: €4,287,529
- Project funding: € 3,424,534

SEVENTH FRAMEWORK PROGRAMME

Max-Planck-Institut für biologische Kybernetik

UNIVERSITY OF LIVERPOOL

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

KIT Karlsruhe Institute of Technology

DLR

Enabling technologies for a short distance commute

mycopter

- Human-Machine Interaction and training issues
- Control and navigation of a single PAV
- Navigation of multiple PAVs, Swarm-technology
- Exploring the socio-technological environment

Max-Planck-Institut für biologische Kybernetik

DLR

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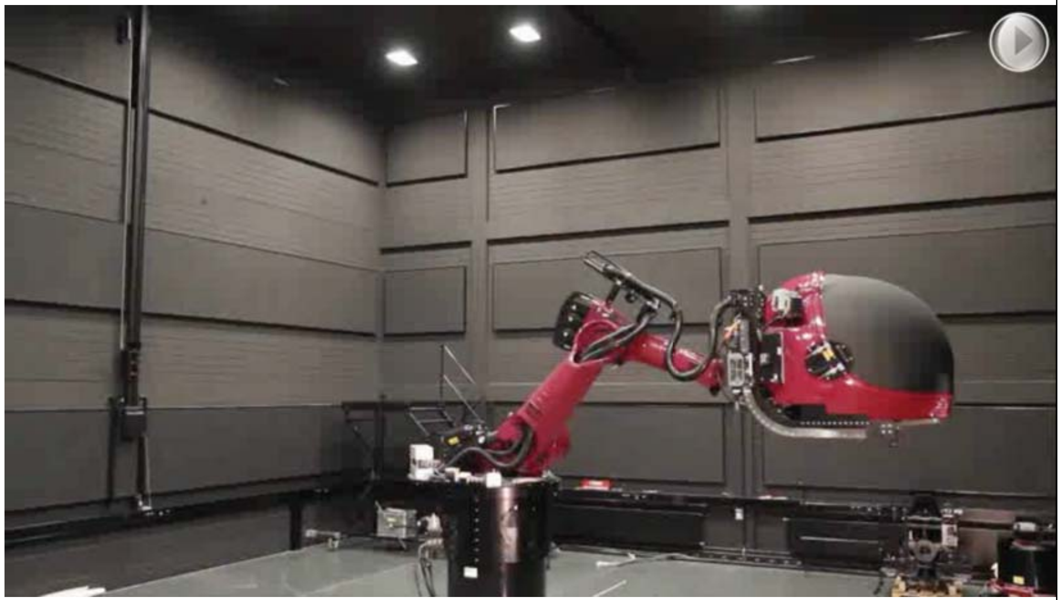
Swiss Federal Institute of Technology Zurich

Novel Human-Machine Interfaces

Make flying as easy as driving

- Multisensory approach: provide additional information with fast and easily understandable cues
  - vision
  - vestibular
  - haptics
  - auditory
- Test Interfaces in simulators
  - MPI CyberMotion Simulator
  - DLR Flying Helicopter Simulator



CyberMotion Simulator, MPI

Novel Human-Machine Interfaces

Novel HMIs are needed for safe and efficient operation of PAVs

- Assess the perceptual and cognitive capabilities of average PAV users
- Evaluations with Highway-in-the-Sky displays
- Support the pilot with haptic cues

Highway in the Sky display, DLR

Training for “ab-initio” PAV users

Develop training requirements for PAV users

- Develop a model that provides very good handling qualities for easy flying
- Determine the level of training with non-pilots / car drivers
- Investigate **emergency** situations and the implications for training

Heliflight-R, The University of Liverpool

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

A novel approach to control

Develop robust novel algorithms for *vision-based* control and navigation

Vision-aided localisation and navigation

- Estimate position in dynamic environments
- Build a 3D map for autonomous operation

Ascending Technologies GmbH

Out of the Box, EC 2007

Markus W. Achtelik, ETH Zürich

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Vision-aided automatic take-off and landing

No ground based landing guidance, everything on board

- Proper landing place assessment and selection are paramount for safe PAV operations
- Onboard surface reconstruction to recover 3D surface information using a single camera
- Autonomous landing with visual cues

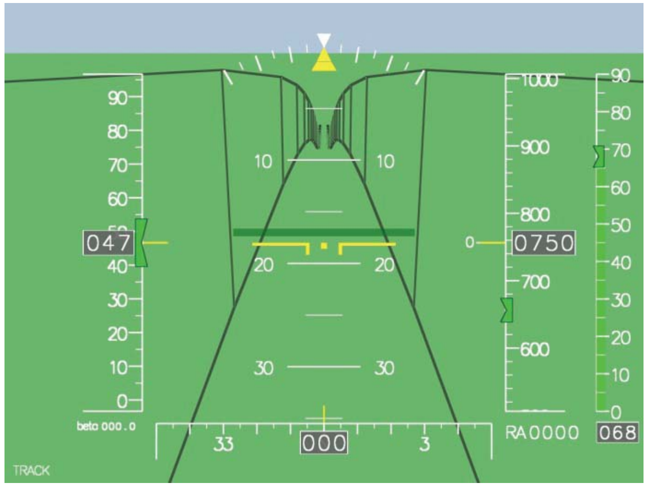
Landing place detection, EPFL CVLab

Decentralised air traffic control

Formation flying along flight corridors

- Global traffic control strategies require swarming behaviour
- Develop flocking algorithms with UAVs
- Evaluations of a Highway-in-the-Sky human-machine interface

Flocking behaviour



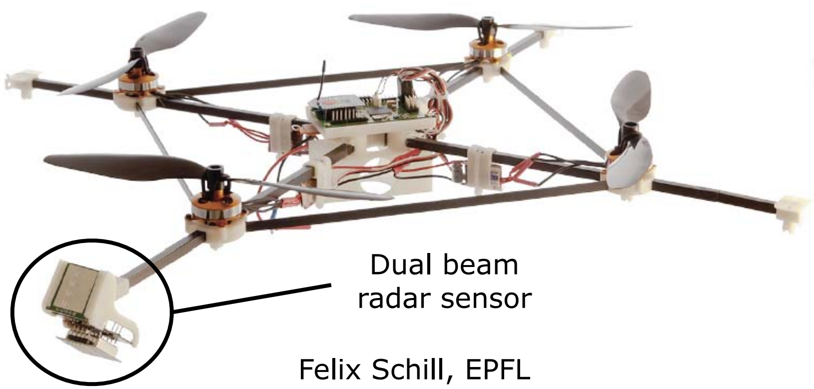
Highway-in-the-Sky, DLR

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Collision avoidance in three dimensions

Novel sensor technologies for onboard sensing

- Determine range and bearing of surrounding vehicles
- Active (laser, sonar, radar) vs. passive sensors (vision, acoustic)
- Evaluation with many small flying vehicles
- Light-weight sensor technology for PAVs



Felix Schill, EPFL

Ascending Technologies GmbH

Explorations of social and economic impact

The biggest hurdle is acceptance by society

- Safety concerns
- Legal issues
- Ecological aspects
- Noise

Out of the Box, EC (2007)

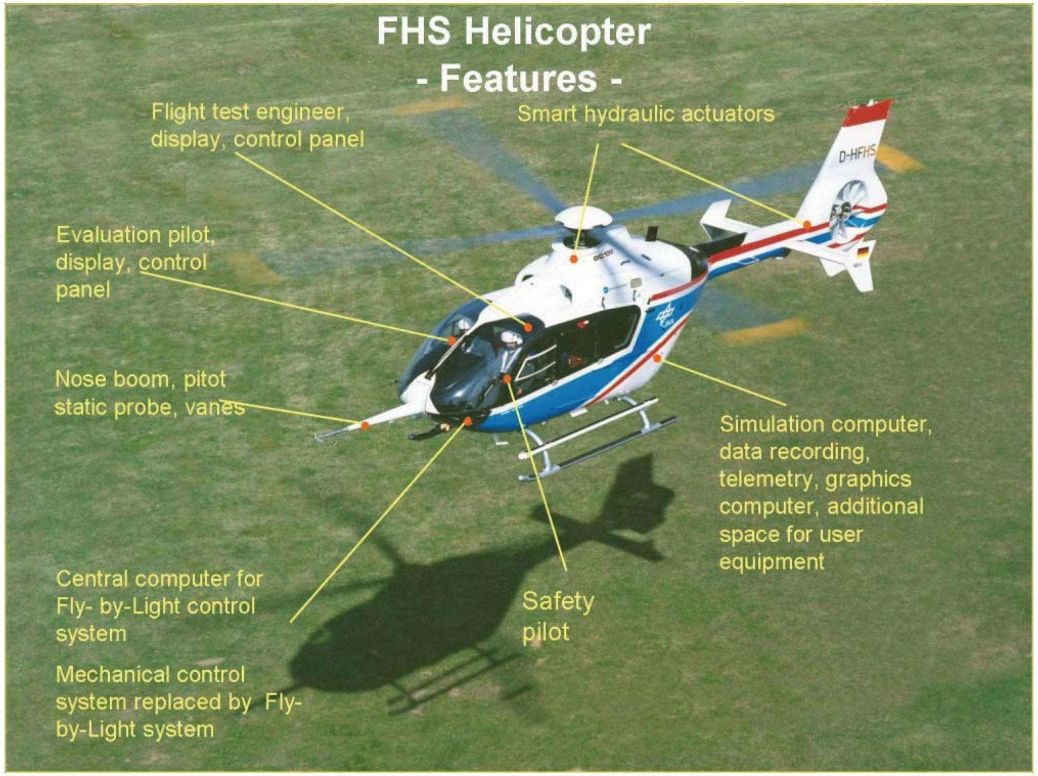
Expectations, requirements and challenges

- Structured interviews with experts
- Focus group workshops on a PAV vision and associated requirements

Focus group workshop, KIT

Experimental validation of proposed technologies

Verify selected developed technologies in flight



Flying Helicopter Simulator, DLR

Flying Helicopter Simulator

- Fly-by-wire / fly-by-light experimental helicopter
- Equipped with many sensors, reconfigurable pilot controls and displays
- Validate HMI concepts and automation technologies

Experimental validation of proposed technologies

Verify selected developed technologies in flight

Flying Helicopter Simulator, DLR

Flying Helicopter Simulator

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- Validate HMI concepts and automation technologies

Strategic impacts of a PATS on the longer term

1. Potentially environmental benefits
   - Spending less time and thus energy in traffic
   - Energy efficiency with future engine technologies
2. Use developed technologies for general aviation
   - Automation, navigation, collision avoidance
3. Enhanced flexibility in urban planning
   - Fewer roads, bridges and less maintenance
   - Less conflicts in land usage

www.famahelicopters.com

André D Conrad, Wikipedia

Past

Skybum, Wikipedia

Present

Out of the Box, EC 2007

Future

My dream PAV

An envisioned Personal Aerial Vehicle, Gareth Padfield, Flight Stability and Control

The enthusiastic myCopter team will help to make my dream come true

Thanks to the rest of my team to keep the lab running while I have a good time at Korea University