AEROWORKS: Collaborative Aerial Robotic Workers

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Automating Infrastructure I&M

- Annual investments on the infrastructure sector represent a significant percentage of the GDP of developed and developing countries:
  - 3.9% of the GDP for the old EU states
  - 5.07% of the GDP for the new EU states
  - 9% of the GDP for China

There is need

There is market

I&M is also an FAA-priority

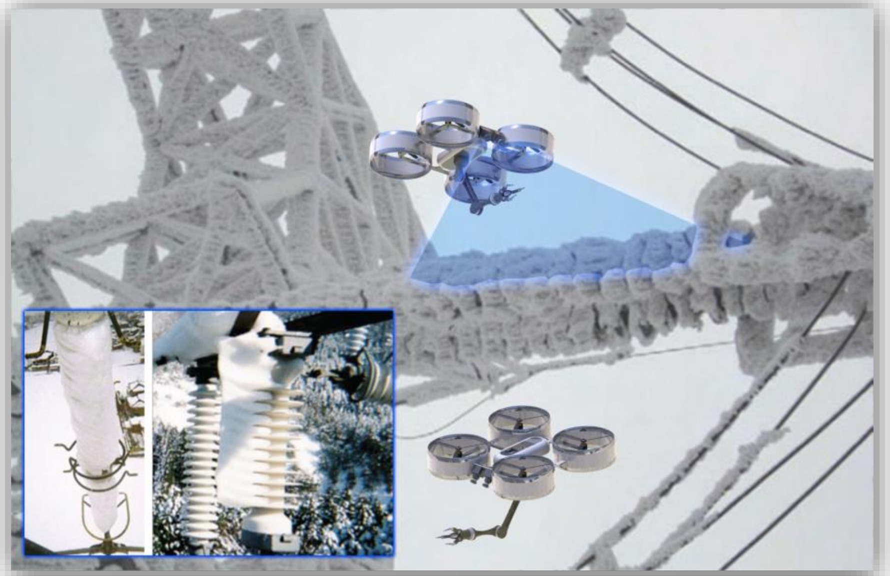
Automating Infrastructure I&M

- To automate infrastructure inspection and maintenance, AEROWORKS introduces a new concept for service robotics:
  - **Collaborative Aerial Robotic Workers:** A new class of aerial robots with the perception capabilities, the manipulation dexterity, the autonomy levels and guaranteed safety to conduct high fidelity inspections, risk assessment and meaningful maintenance tasks.

Automating Infrastructure I&M

A new concept: **A**erial **R**obotic **W**orkers

- Service robotics of superior autonomy, perception/3D reconstruction capabilities, physical work-task execution capacity, unsupervised multi-robot collaboration for complex task execution.
- No more sensitive and fragile Unmanned Aerial Vehicles: aerial robots that correspond to unique and versatile intelligent tools at the disposal of the human worker.



What is there and what is missing

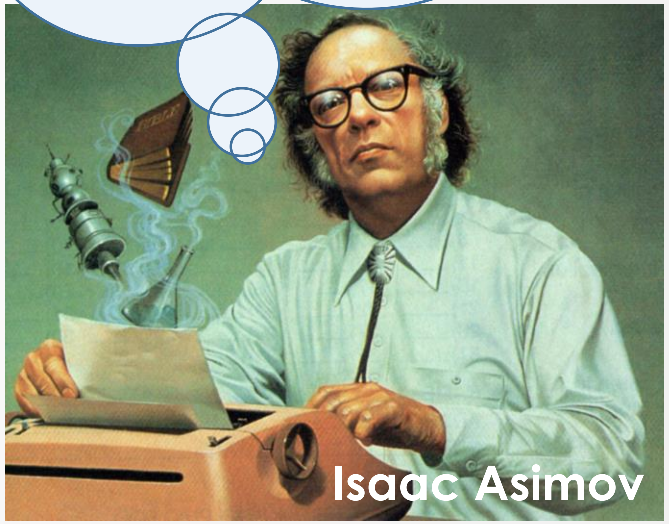
- There are several things we can do

- But also levels of autonomy, maneuverability and dexterity we haven't reached

The challenges on the way

- Can we trust an aerial robot flying in the urban landscape?
- Can we trust an aerial robot flying in the controlled national airspace?
- Can we ensure collision avoidance?
- Can we assign complex infrastructure inspection tasks to aerial robots?
- Can aerial robots be something more than a flying camera?
- Can we operate aerial robots without having special skills?

- a robot may not injure a human being or, through inaction, allow a human being to come to harm
- a robot must obey orders given it by human beings except where such orders would conflict with the first law
- a robot must protect its own existence as long as such protection does not conflict with the first or second law



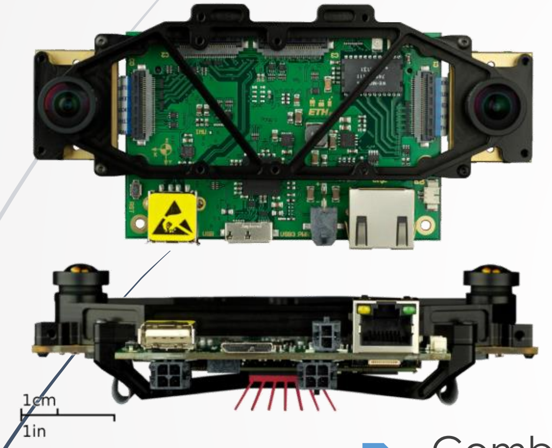
Providing inspiration to roboticists since 1950

AEROWORKS Research Objectives

- Superior localization and mapping capabilities and real-time dense reconstruction of the environment.
- Advanced flight control and aerial manipulation for work-task execution. Agile flight and dexterous manipulation via body/end-effector coordination
- Autonomous structural inspection path-planning intelligence without prior perfect knowledge of the structure.
- Collision-free navigation via tight coupling of the perception-navigation loop.
- Multi-robot mapping and multi-robot collaboration for inspection and physical work-task execution.

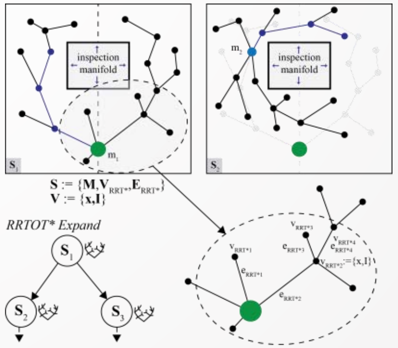
The ARWs platform

- Visual Inertial-Sensor



- Combined High- and Low-level Control and processing power
- Versatile algorithm deployment

- Path-planning algorithms



- Robotic arm

A collaborative team

- Collaborative mapping

- Collaborative manipulation

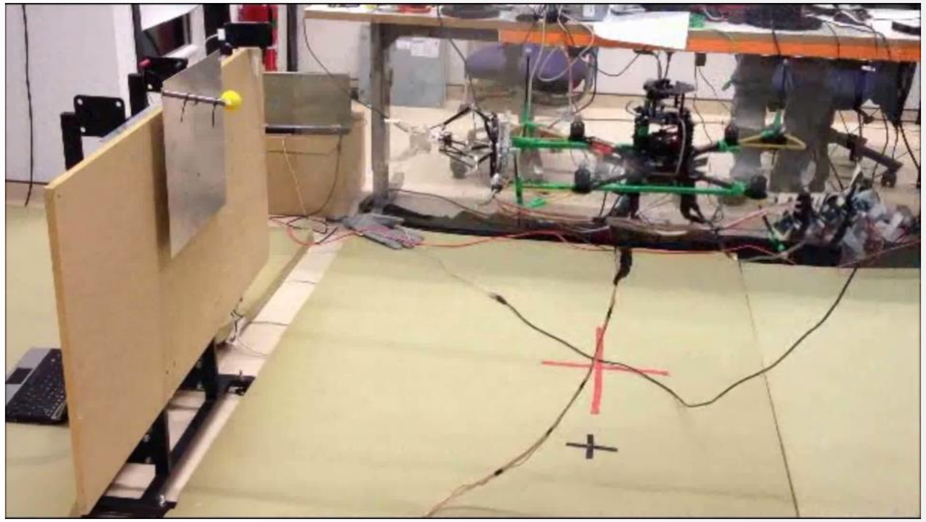
- Decentralized task assignment

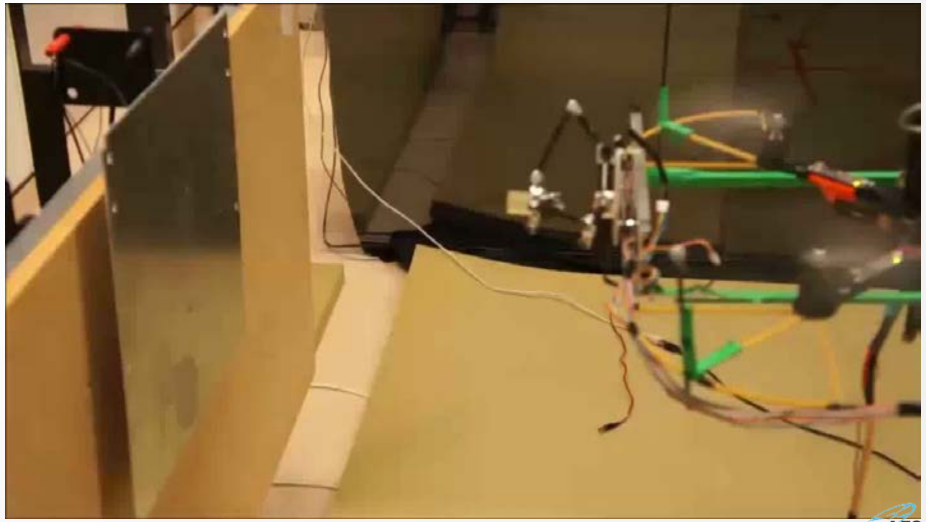
- Collaborative exploration and inspection

- Reconfiguration

Starting point and Goals: Aerial Manipulator

- **Mechanical Design**
  - Minimization of moving mass
  - Compliance to prevent high impact forces
  - Design around a very lightweight MAV
- **Sensing:**
  - Integration of the required sensory setup to allow dexterous manipulation control
  - Use of the perception capabilities of the aerial robot for manipulation control.





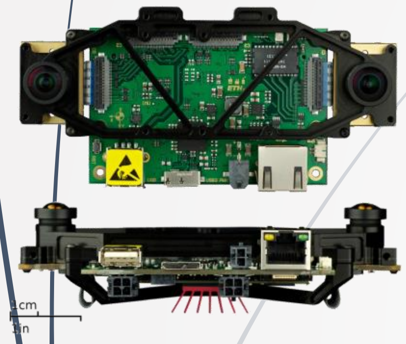
[1]

Starting point and Goals: Control

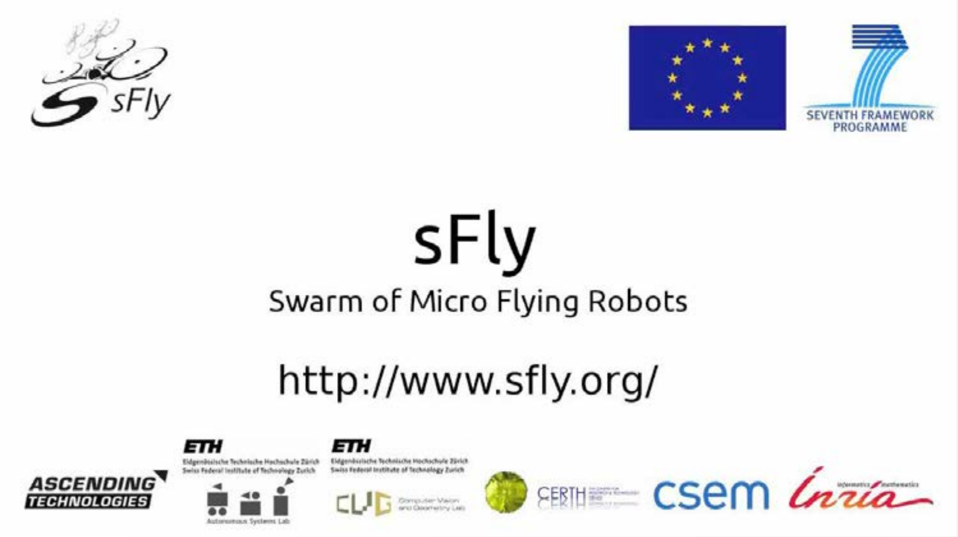
- Agile flight and dexterous physical work-task execution control.
- Stability during generalized interaction/manipulation
- Robustness against rough and unpredicted collisions of the manipulator
- Treatment of the aerial vehicle – manipulator control problem as a whole. Human hand and body paradigm.
- Primitives of co-manipulation established already at the level of the single robot control by understanding the aiding or hindering role of externally applied forces and moments.

[2]

Starting point and Goals: Perception



- Robust localization and high-fidelity dense reconstruction of the environment.
- Loop closure and fusion with GPS updates when available.
- Operation very close to structure occlusions, ambiguity, small amount of features to track.
- All developments will be based on the VI-Sensor, a unique system that implements the baseline solutions and provides the framework for beyond-the-state-of-the-art research. [3]

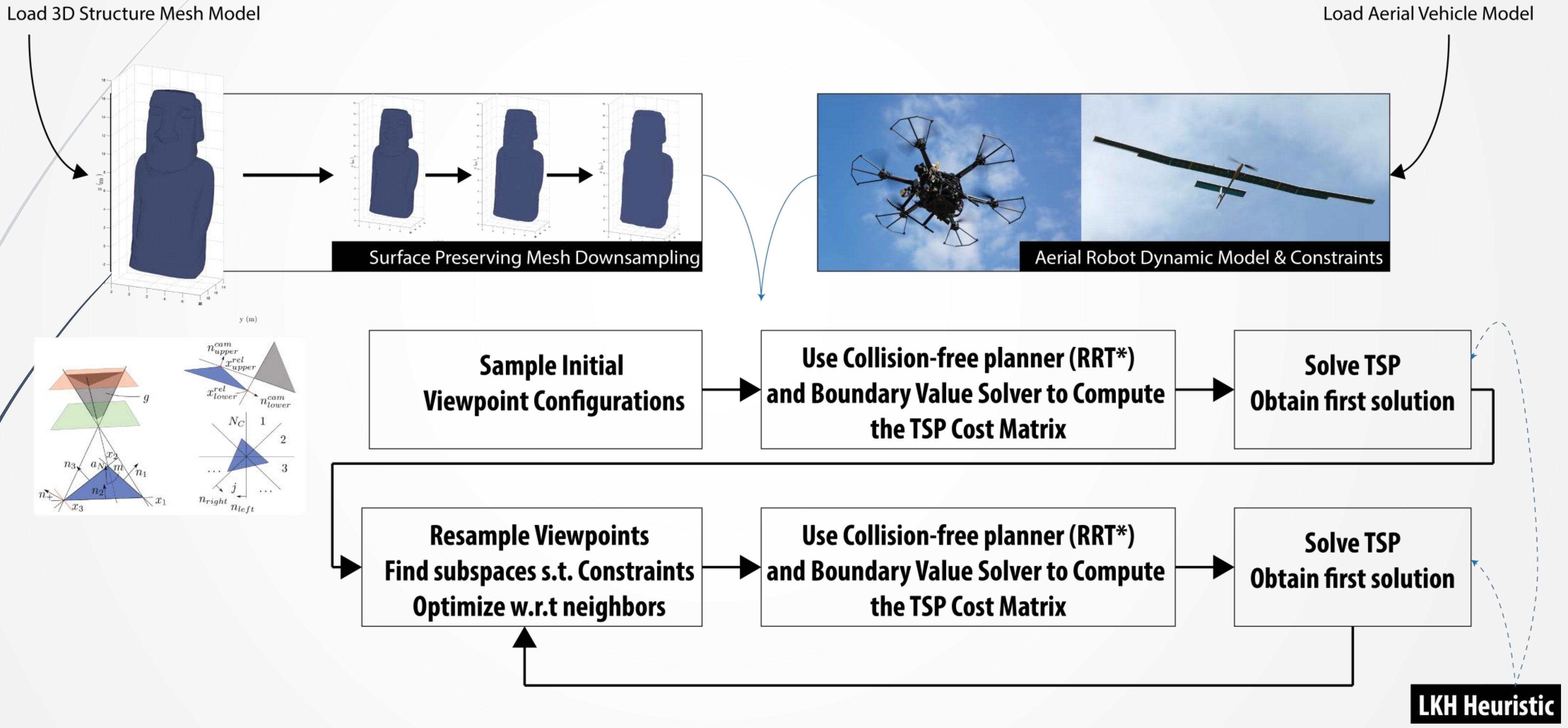


Starting point and Goals: Path Planning

- Inspection path-planning account for uncertainties on the initial model of the structure.
- Exploration path-planning for completely unknown environments
- Vehicle body/manipulator collaborative planning for dexterous manipulation.
- Real-time agile collision-free navigation in cluttered environments.

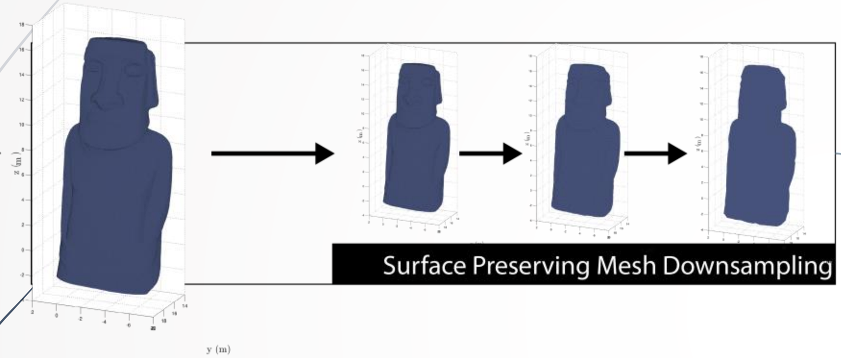
[4]

Efficient Structural Inspection Path Planning

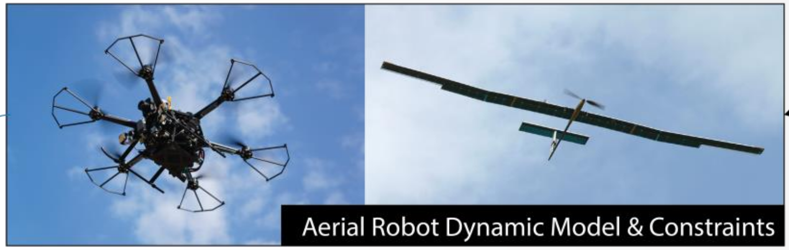


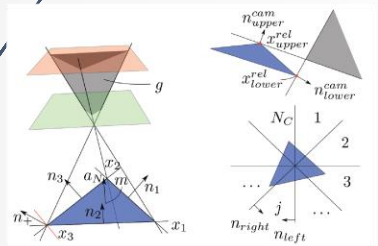
Efficient Structural Inspection Path Planning

Load 3D Structure Mesh Model



Load Aerial Vehicle Model





Sample Initial Viewpoint Configurations → **Use Collision-free planner (RRT*) and Boundary Value Solver to Compute the TSP Cost Matrix** → **Solve TSP Obtain first solution**

Resample Viewpoints Find subspaces s.t. Constraints Optimize w.r.t neighbors → **Use Collision-free planner (RRT*) and Boundary Value Solver to Compute the TSP Cost Matrix** → **Solve TSP Obtain first solution**

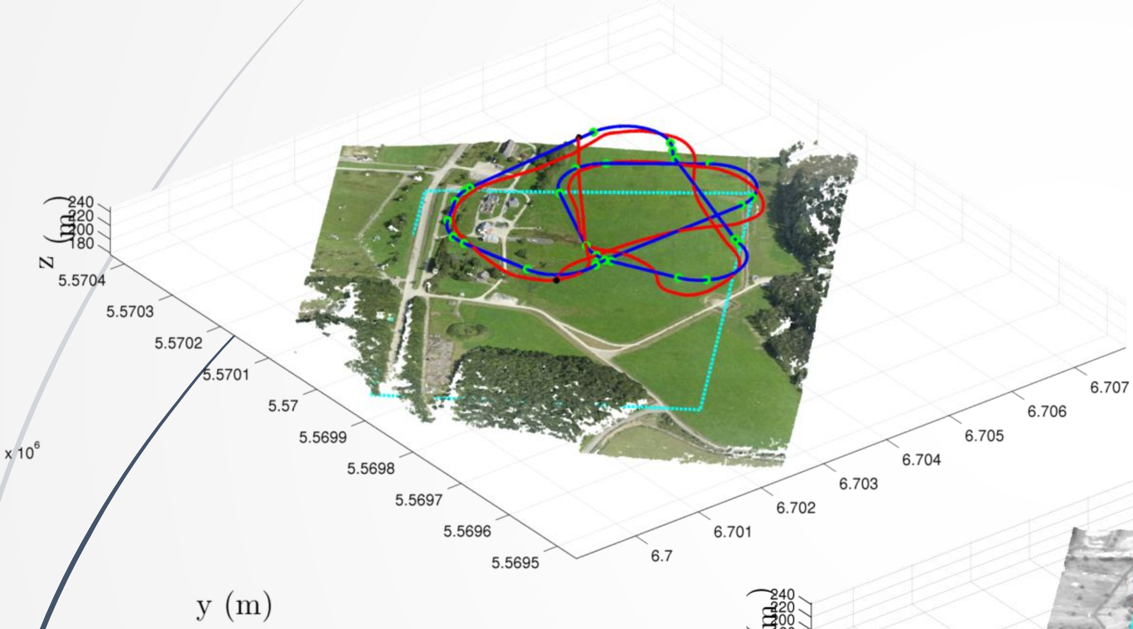
LKH Heuristic

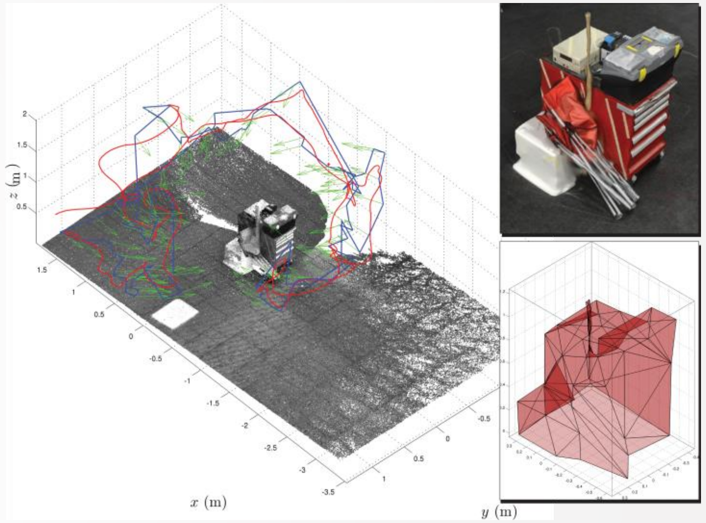
- Allow Path Improvement

Open-source tool released

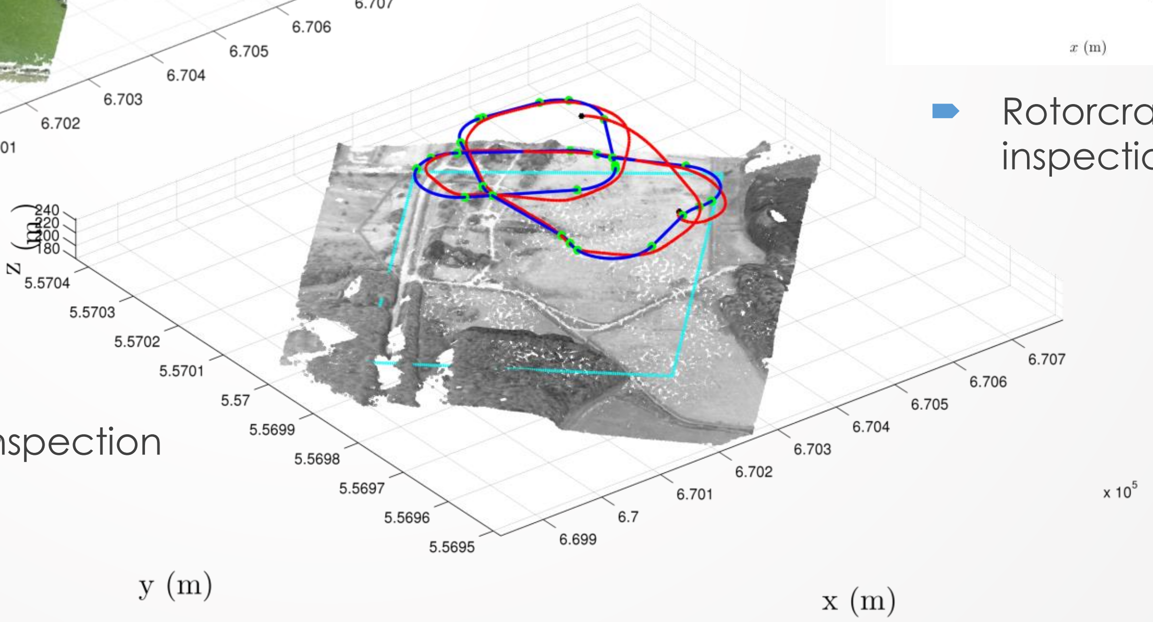
Efficient Structural Inspection Path Planning

- Fixed-wing UAV Nadir camera mounting inspection path planning





- Rotorcraft MAV – oblique view inspection path planning



- Fixed-wing UAV Oblique view inspection path planning


Structural Inspection Path Planning via Iterative Viewpoint Resampling
with Application to Aerial Robotics
Andreas Bircher, Kostas Alexis, Michael Burri, Phlipp Oettershagen, Sammy Omari, Thomas Mantel and Roland Siegwart
ETH

Starting point and Goals: Multi-Robot

- Collaborative structural inspection and area exploration
- Collaborative mapping and 3D reconstruction
- Decentralized task assignment and team reconfiguration **[5]**
- Handle heterogeneity
- Collaborative Aerial Manipulation

AEROWORKS demonstration plan

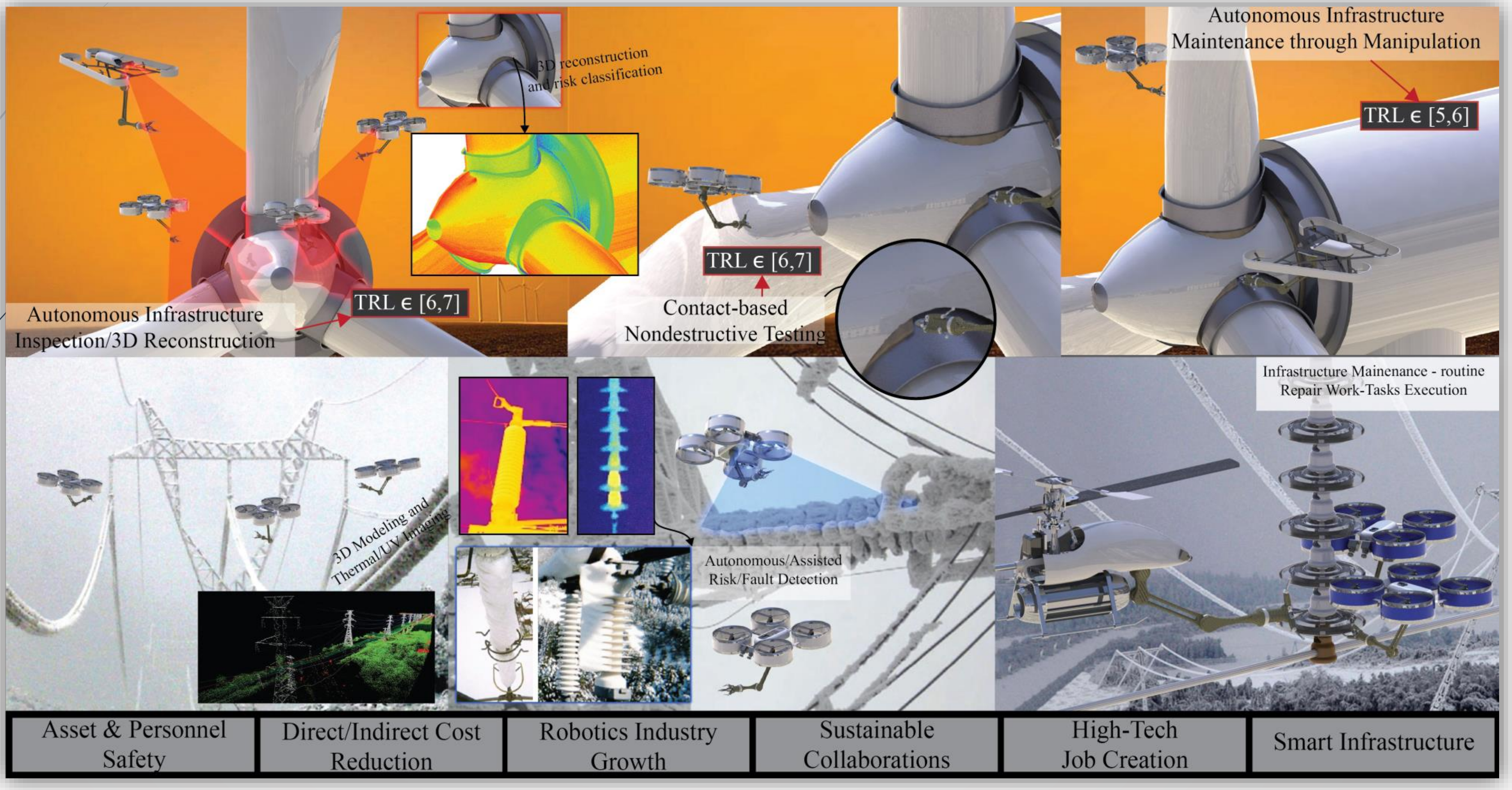
- **Demonstration plays a major role for the AEROWORKS project**
  - Technology validation experiments in controlled environments
  - Systems and Technology validation experiments in realistic mock-ups of infrastructure
  - Public systems and technology demonstrations in real-life infrastructure assets
  - Operational tests of the AEROWORKS robotic team, evaluation of the maturity level of each technology and definition of what is to be investigated from further research projects.
  - Open-dataset releases

- **Performance assessment within the whole project evolution:**
  - Evaluation of the capabilities of each technological component
  - Evaluation of the integrated aerial robotic workers
  - Validation of the operational capacity of the AEROWORKS robotic team

The AEROWORKS impact in a nutshell

or why are we useful to those that indirectly fund us?

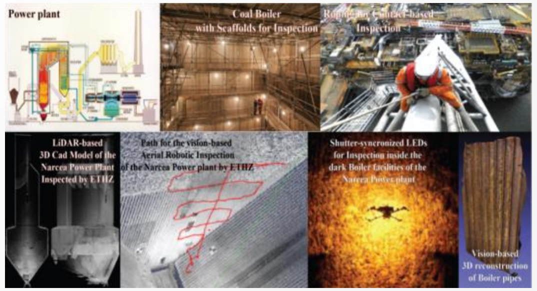
The AEROWORKS impact in a nutshell



Example Application Scenarios

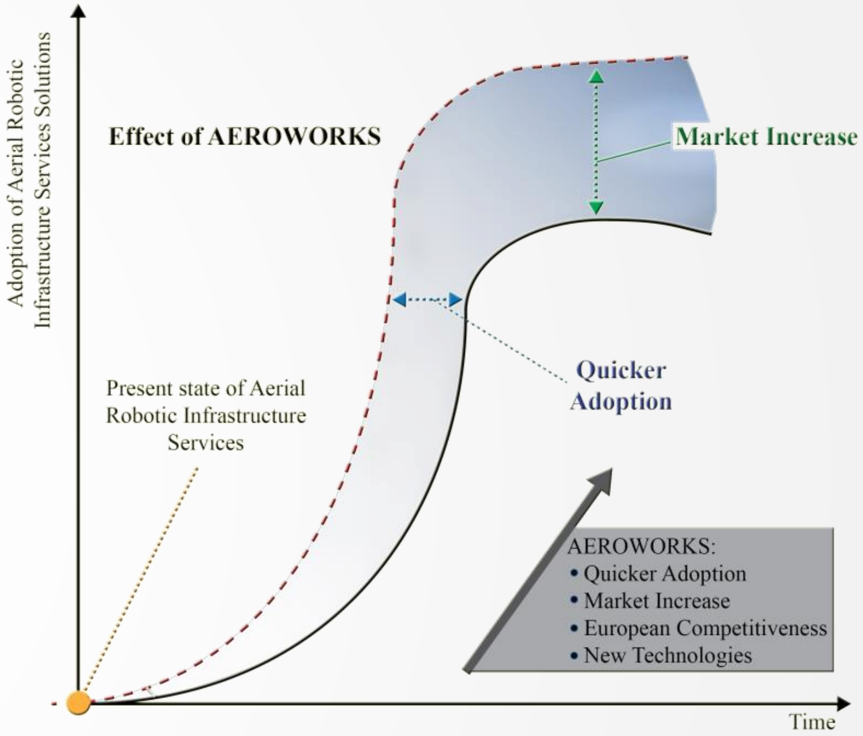
- **S1: Wind Turbines Inspection**
  - Considered for final demo
- **S2: Power Network Inspection**
- **S3: Pipework Inspection**
- **S4: Power Plants Inspection**
- **S5: Water Dam Inspection**
- **Two will be picked to perform relevant demonstrations**

- Focus on open-dataset releases to establish collaboration with other research communities (e.g. computer graphics)



AEROWORKS targeted economic impact

- **Short-term:** utilization of the AEROWORKS robotic team by AIR and SKL
- **Mid-term:** wide integration of robotic products based on the AEROWORKS contributions to the infrastructure service business.
- **Main goal:** strengthening of the European Service Robotics Sector
- **AEROWORKS aims for:**
  - an increased take-up of marketable robotic technologies
  - rising awareness across the community about what robotics can accomplish
  - creation of a sustainable value chain between academia, robot developers, service providers and asset owners
  - positive economic impact on the competitiveness and growth of infrastructure service businesses in Europe
  - strengthened competitiveness of the European Robotics Industry
  - increased high-quality Job Creation without endangering job positions
  - a significant contribution to the society-critical infrastructure sector



The AEROWORKS Consortium

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ASCENDING TECHNOLOGIES

ALSTOM Inspection Robotics

Skybotix UAV NAVIGATION SOLUTIONS

SKELLEFTEÅ kraft

	Manipulation	UAV Design	Control	Estimation	Perception	Path-Planning	Multi-Robot Col-laboration	Teleoperation	Wireless Coms.	Sensors Development	Robots Development	Service Robotics Market share	Infrastructure Management	Infrastructure Services
LTU	✓		✓			✓	✓		✓	✓				
ETHZ		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
KTH			✓			✓	✓							
UT	✓		✓	✓				✓			✓			
UEDIN				✓	✓	✓								
UPAT		✓	✓				✓				✓			
ASC		✓	✓	✓					✓	✓	✓	✓		
SBX		✓	✓	✓	✓			✓		✓				
AIR											✓	✓		✓
SKL													✓	✓

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- Website: http://www.aeroworks2020.eu/
- Publications: http://www.aeroworks2020.eu/code-releases/
- Code-Releases: http://www.aeroworks2020.eu/code-releases/
  - **First already out!** https://github.com/ethz-asl/StructuralInspectionPlanner
- Open-Data: http://www.aeroworks2020.eu/open-data/
  - **First already out!** https://github.com/ethz-asl/StructuralInspectionPlanner/wiki/Example-Results
- Video Channel: http://www.aeroworks2020.eu/videos/
- Social media
- Conferences and Workshops
- **Talk to us – we are looking for further collaborations!**

Indicative References

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- [3] D. Scaramuzza, M. C. Achtelik, L. Doitsidis, F. Fraundorfer, E. Kosmatopoulos, A. Martinelli, M. W. Achtelik, M. Chli, S. Chatzichristofis, L. Kneip, D. Gurdan, L. Heng, G.H. Lee, S. Lynen, L. Meier, M. Pollefeys, A. Renzaglia, R. Siegwart, J. C. Stumpf, P. Tanskanen, C. Troiani and S. Weiss, "Vision-Controlled Micro Flying Robots: From System Design to Autonomous Navigation and Mapping in GPS-Denied Environments, IEEE RAS Magazine, September, 2014
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- [5] Meng Guo, Michael M. Zavlanos and Dimos V. Dimarogonas, Controlling the Relative Agent Motion in Multi-Agent Formation Stabilization, IEEE Transactions on Automatic Control, Vol. 59, No. 3, pp. 820-826, March 2014.

Thank you!

Please ask your question!