Univ. Udine, December 2014

Collaborative Small-Scale UAVs

Project Overview

ALPEN-ADRIA UNIVERSITÄT
KLAGENFURT | WIEN GRAZ

FAKULTÄT FÜR TECHNISCHE WISSENSCHAFTEN

Institut für Vernetzte und Eingebettete Systeme

Bernhard Rinner

Motivation

- Target application disaster management
  - Support first responders in disasters with multiple UAVs
  - Provide latest and relevant information about the scene
  - Autonomously flying, networked, collaborating UAVs
- Multidisciplinary research team
  - 4 research groups at Klagenfurt University
  - Several guest researchers
  - Spin-off company

Collaborative Microdrones

- Develop autonomous multi-UAV system for aerial reconnaissance
- Up-to-date aerial overview images are helpful in many situations:
  "Google Earth with up-to-date images in high resolution"

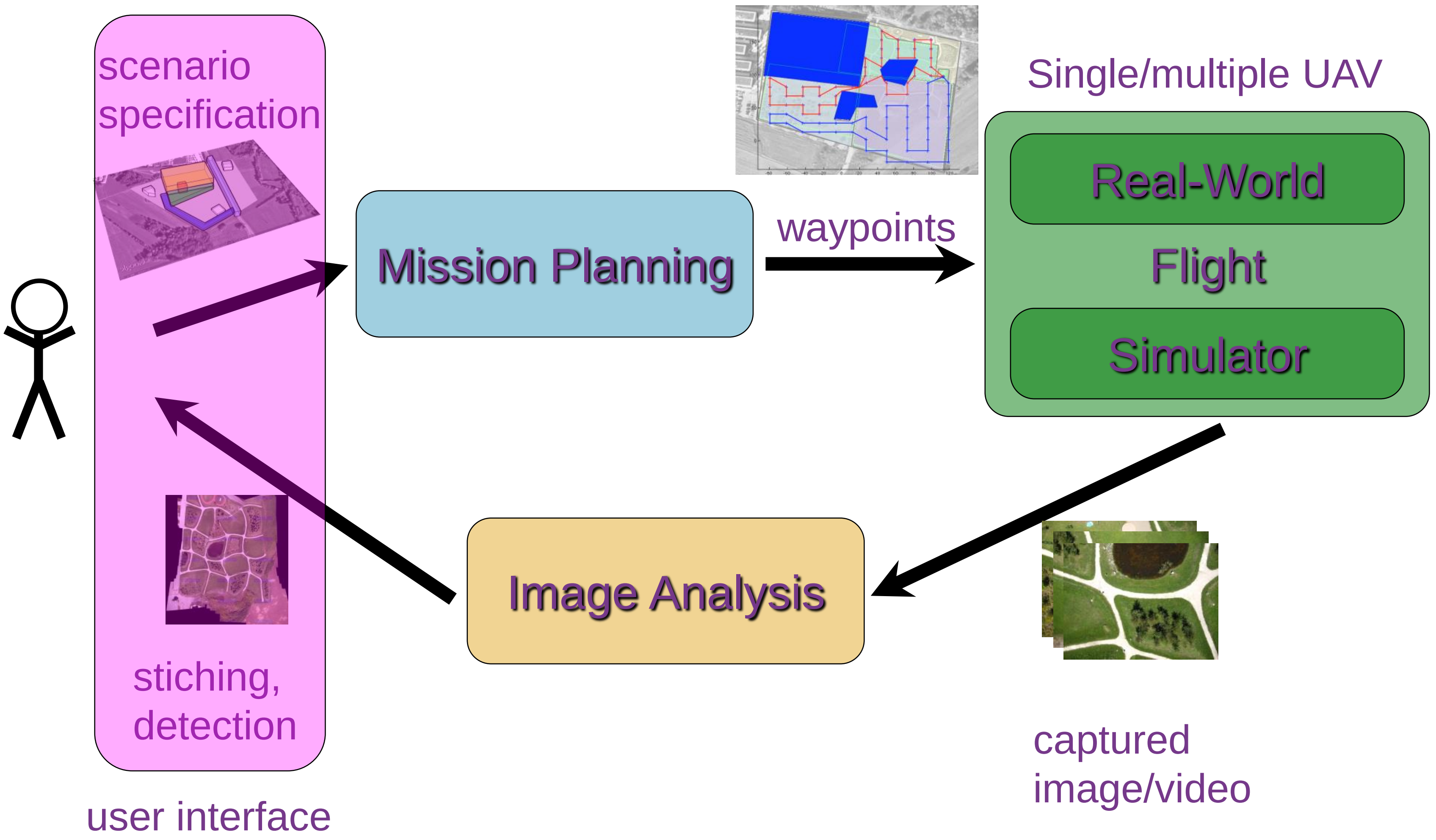
- Small-scale quadcopter platform with onboard sensors and computation
- GPS receiver for autonomous waypoint flights
- Generic framework not bound to specific UAV

Key Challenges

ALPEN-ADRIA UNIVERSITÄT KLAGENFURT | WIEN GRAZ
Lakeside Labs

- Increase autonomy
  - Control and coordination of multiple UAVs
  - High-level interaction with user
- Provide prompt response to user
  - Provide preliminary results fast and improve over time
- Deal with strong resource limitations
  - Flight time, payload, computation and communication
  - Limited sensing capabilities

Autonomous UAV Operation



Key Questions

- How to generate and update movement routes for the UAVs?
  - Achieve multiple optimization goals
  - Deal with changes in the environment
- How to setup a wireless UAV network?
  - Provide networking coverage
- How to generate the mosaic image?
  - Apply incremental image stiching
  - Combine RGB and thermal images

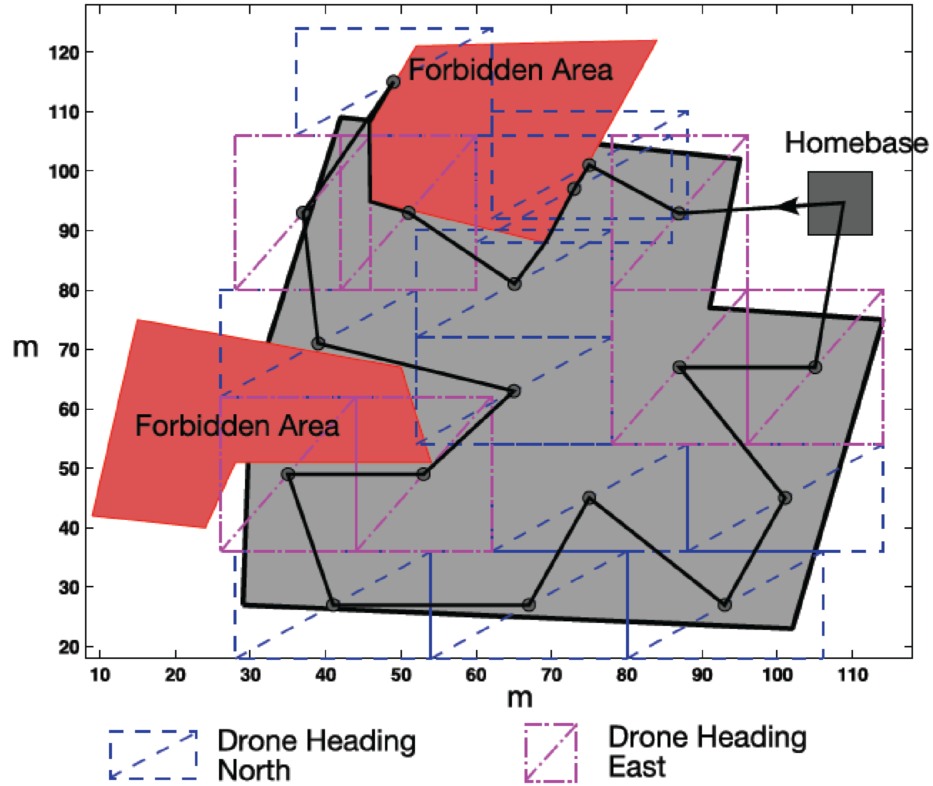
- System integration and demonstration

Generation of UAV Routes

	Non-cooperative	Cooperative
Deterministic	UAV has a **predefined route** that is **independent** of other UAV paths.	UAV has a **predefined route** that **depends** on other UAV paths.
Dynamic	UAV has an *a priori* **unknown route** that is **independent** of other UAV paths.	UAV has an *a priori* **unknown route** that **adapts** to other UAV paths.

Where to take the pictures

- Compute picture points from the user-specified “area of interest”
  - 3D flight corridor is input
  - Minimize number of picture points while satisfying resolution and overlap requirements
- Derive optimal solution by ILP
  - NP complete problem
- Apply heuristics
  - Iterative approach



Quaritsch et al. Networked UAVs as aerial sensor network for disaster management applications. *Elektrotechnik & Informationstechnik.* 2010

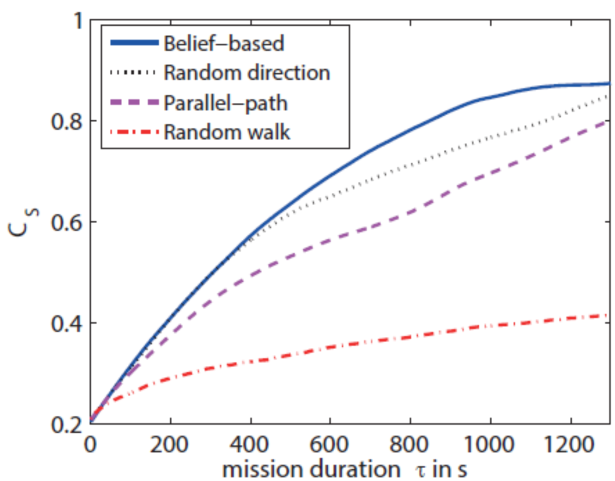
Deterministic Route Planning

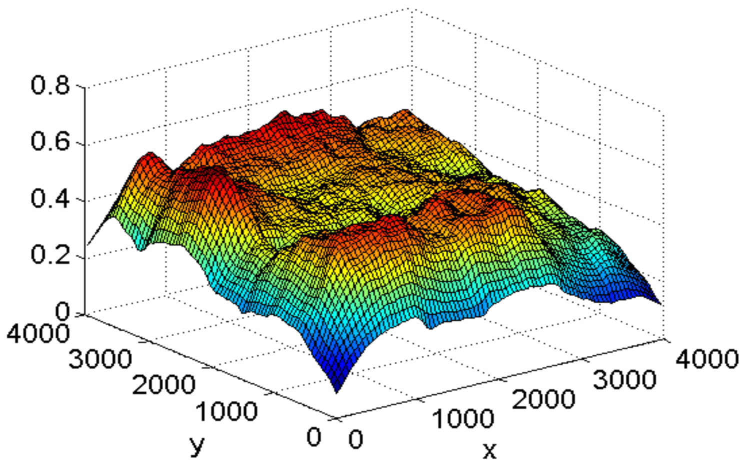
- Compute routes R_i (sequence of picture points) for all UAVs
  - R1: Covering the area as fast as possible
  - R2: Continuously monitoring the area
- Considering limitations on speed and flight time
  - Return to base station (eventually change batteries)
- Developed two different heuristics for global planning
  - Fast and only small deviation from optimum
  - Adaptation by recomputing routes from current situation

Mersheeva et al. Routing for Continuous Monitoring by Multiple Micro UAVs in Disaster Scenarios. In *Proc. ECAI.* 2012

Probabilistic Route Planning

- Each UAV determines locally its route and exchanges information when it is close to other UAV
  - Simple local planning, eg., random walk, parallel-path, belief-based
  - Online adaptation
- Simulation-based studies

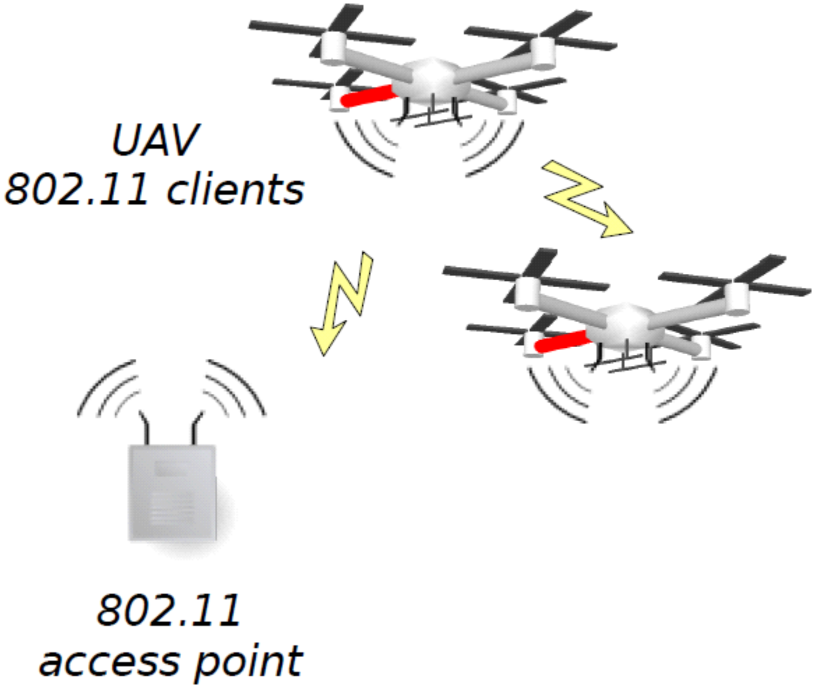




Yanmaz et al. Area Coverage with Unmanned Vehicles: A Belief-based Approach In *Proc. VTC.* 2010

Networked Aerial Robots

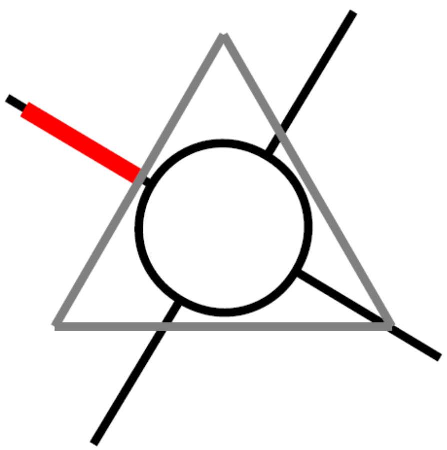
- Information exchange between
  - Base station and UAVs
  - Inter-UAV communication
- Wireless networking in 3D space
  - Different positions/elevation levels
  - UAV Orientation (yaw, tilt, roll)
- Establish reliable connection with standard protocols
  - High data rates required
  - IEEE 802.11a to avoid interference



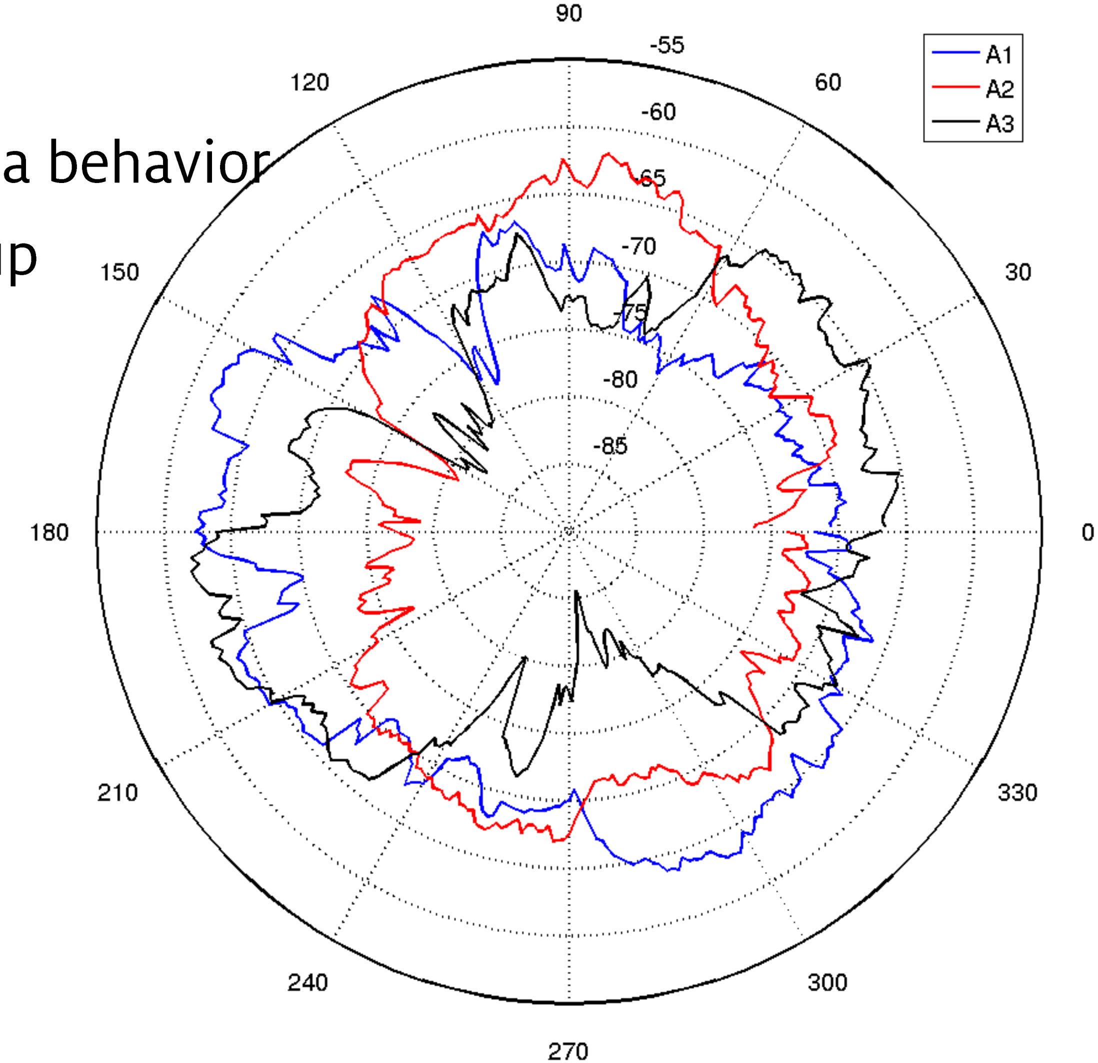
Kuschnig et al. Profiling IEEE 802.11 Performance on Linux-based Networked Aerial Robots. In *Proc. ARW* 2012

Antenna Setup

- Investigate UAV antenna behavior
- Triangular antenna setup
  - 3 dipole antennas
  - UAV position fixed
  - UAV orientation (yaw) to the AP varies



Quadrotor UAV



RSSI on the UAV in dBm (d=100m, h=50m)

Image Mosaicking

ALPEN-ADRIA UNIVERSITÄT KLAGENFURT | WIEN GRAZ
Lakeside Labs

- Problem definition
  - Given n individual images Ii, find image transformations Ti for each Ii

    $$I_{overview} = \bigcup_{i=1}^{n} T_i(I_i)$$

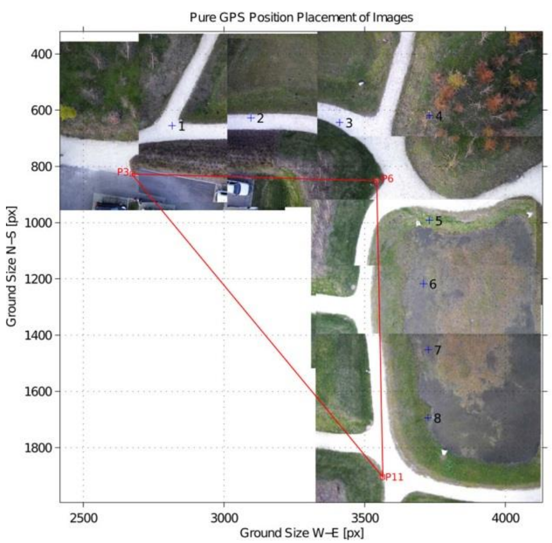
    which maximizes some quality function $\lambda(I_{overview})$

- Two fundamental approaches for finding the transformations
  1. Exploit auxilliary data, i.e., camera's position and orientation (meta data based approach)
  2. Exploit corresponding points within image overlaps (image based approach)

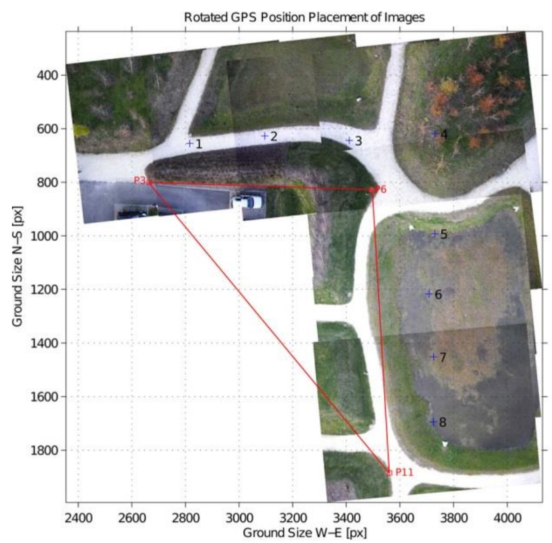
Yahyanejad et al. Incremental Mosaicking of Images from Autonomous, Small-Scale UAVs. In Proc. AVSS. pages 329-336, 2010.

Incremental Image Mosaicking

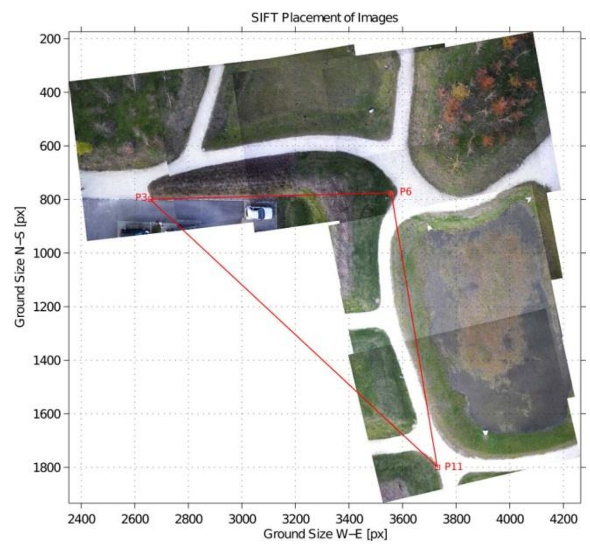
- Start with meta data approach, refine with image-based approach



Position data
(GPS meta data)



Position&orientation data
(GPS & IMU)

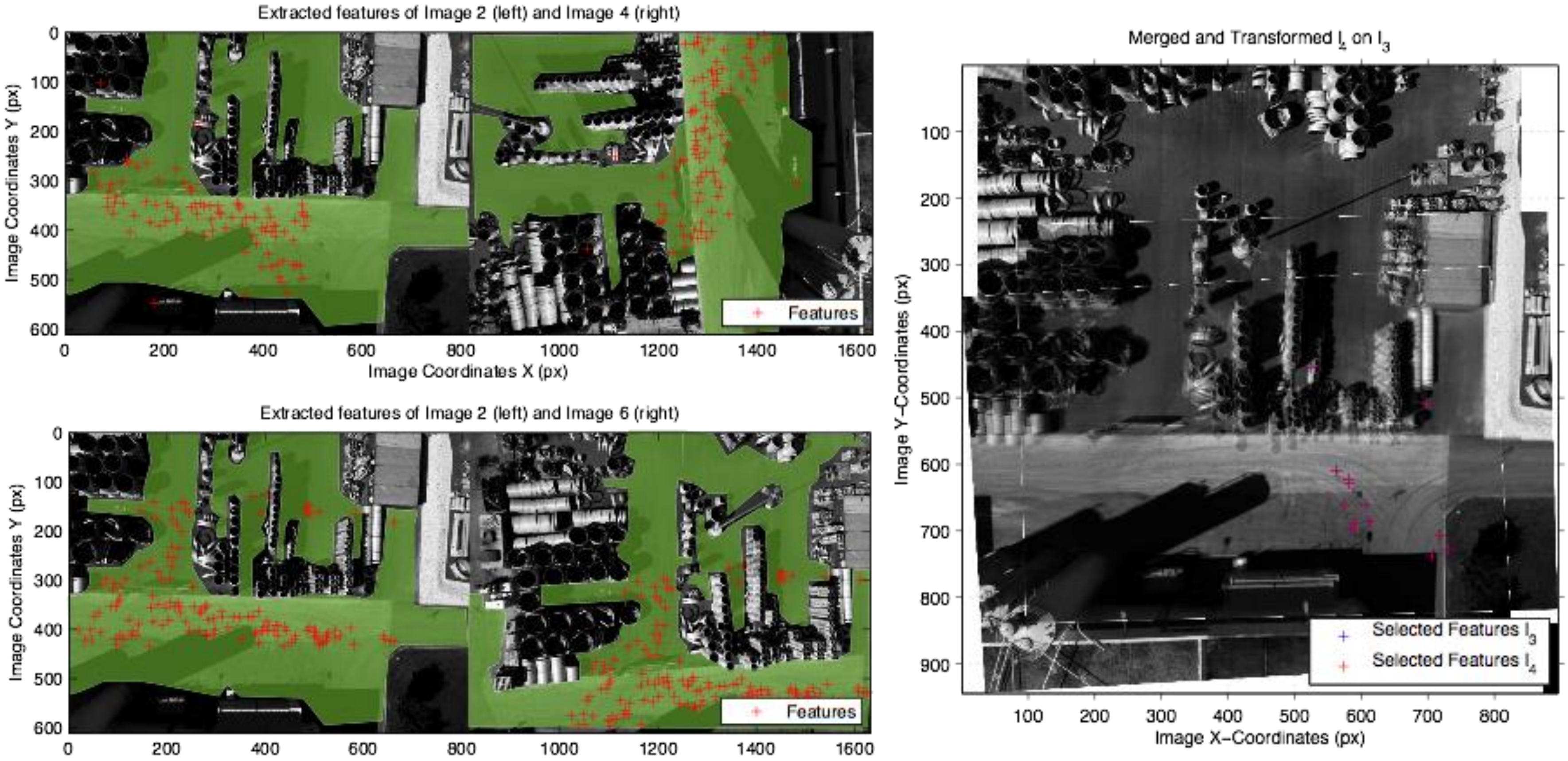


SIFT feature points
(Image data)

Apparatus and method for generating an overview image of a plurality of images using an accuracy information. European patent, EP2423871 (A1), 2012

Structure-based Mosaicking

- Identify corresponding points at the same level by exploiting 3D information



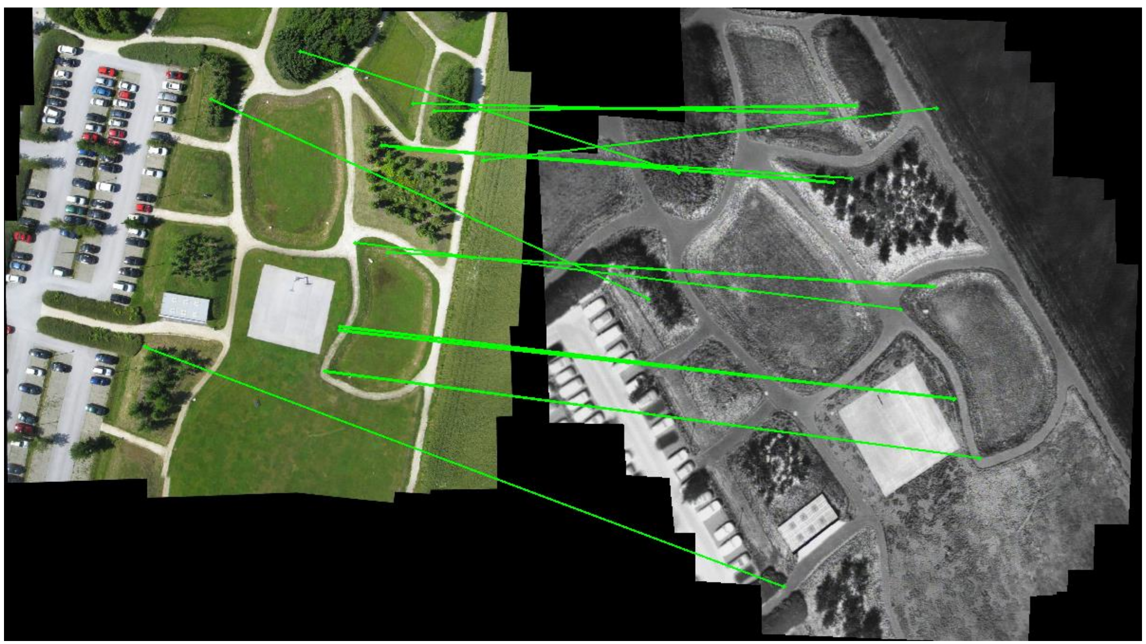
Multi-level Mosaicking

ALPEN-ADRIA UNIVERSITÄT KLAGENFURT | WIEN GRAZ
Lakeside Labs

- Start with low-resolution registration
- Expand to high-resolution images

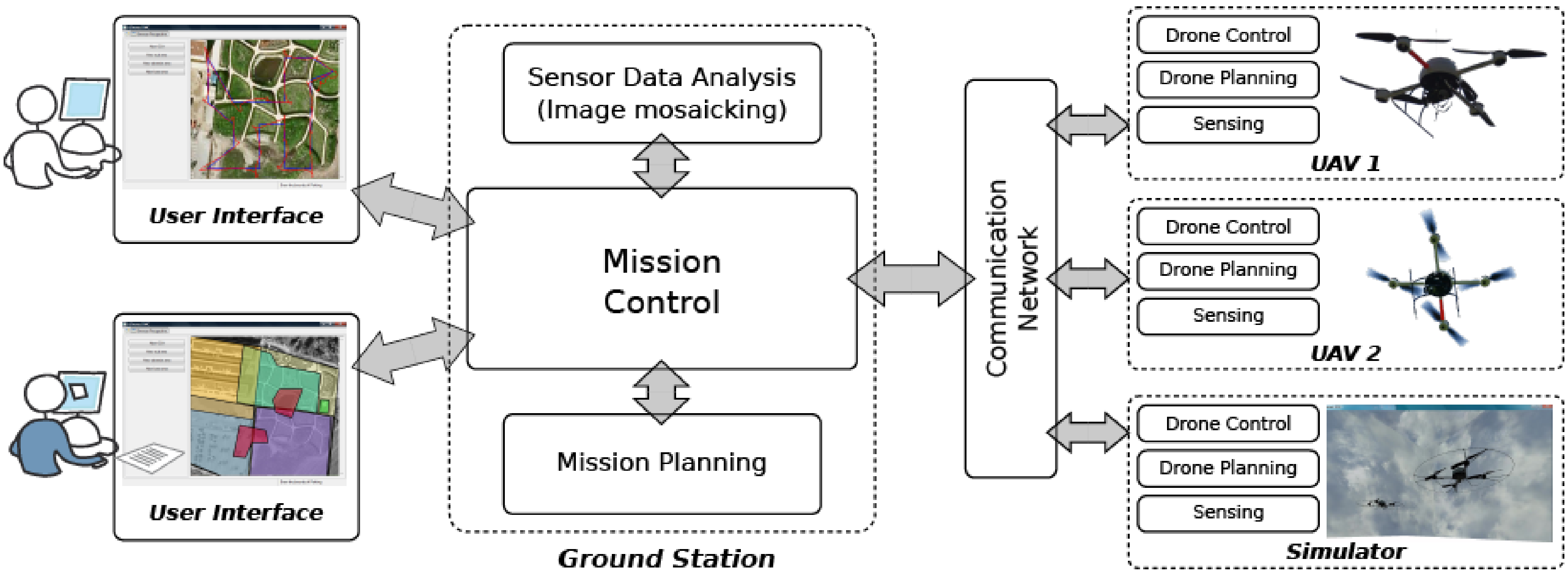
Inter-spectral Mosaicking

- Register thermal and RGB images captured by different UAVs
- Two approaches to overcome challenging feature matching
  - Register RGB and thermal mosaics
  - Exploit depth map as features



System Integration

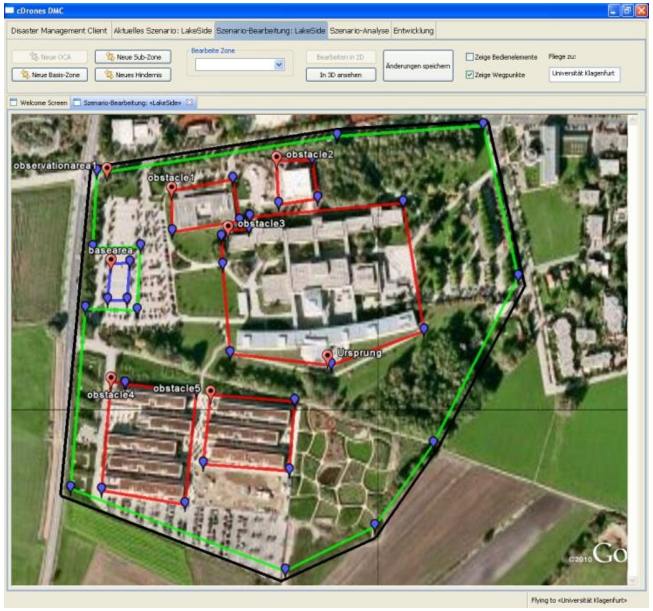
- Deployment as distributed system
  - User interfaces – ground control - UAVs

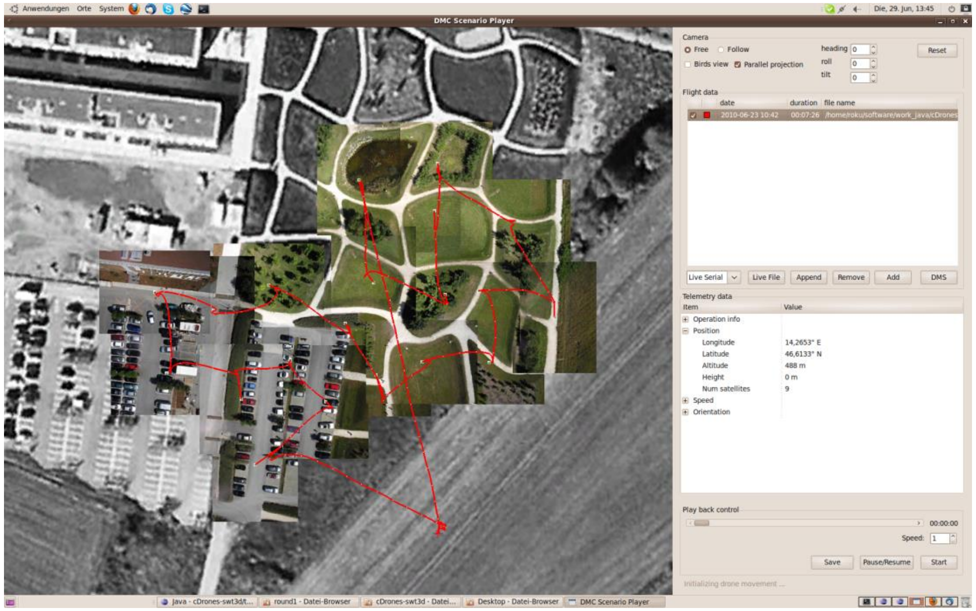


Quaritsch et al. FAMUOS: A Multi-UAV System for Aerial Reconnaissance in Rescue Scenarios. In *Proc. ARW*. 2011.

„Google-like“ User Interface

ALPEN-ADRIA UNIVERSITÄT KLAGENFURT | WIEN GRAZ
Lakeside Labs

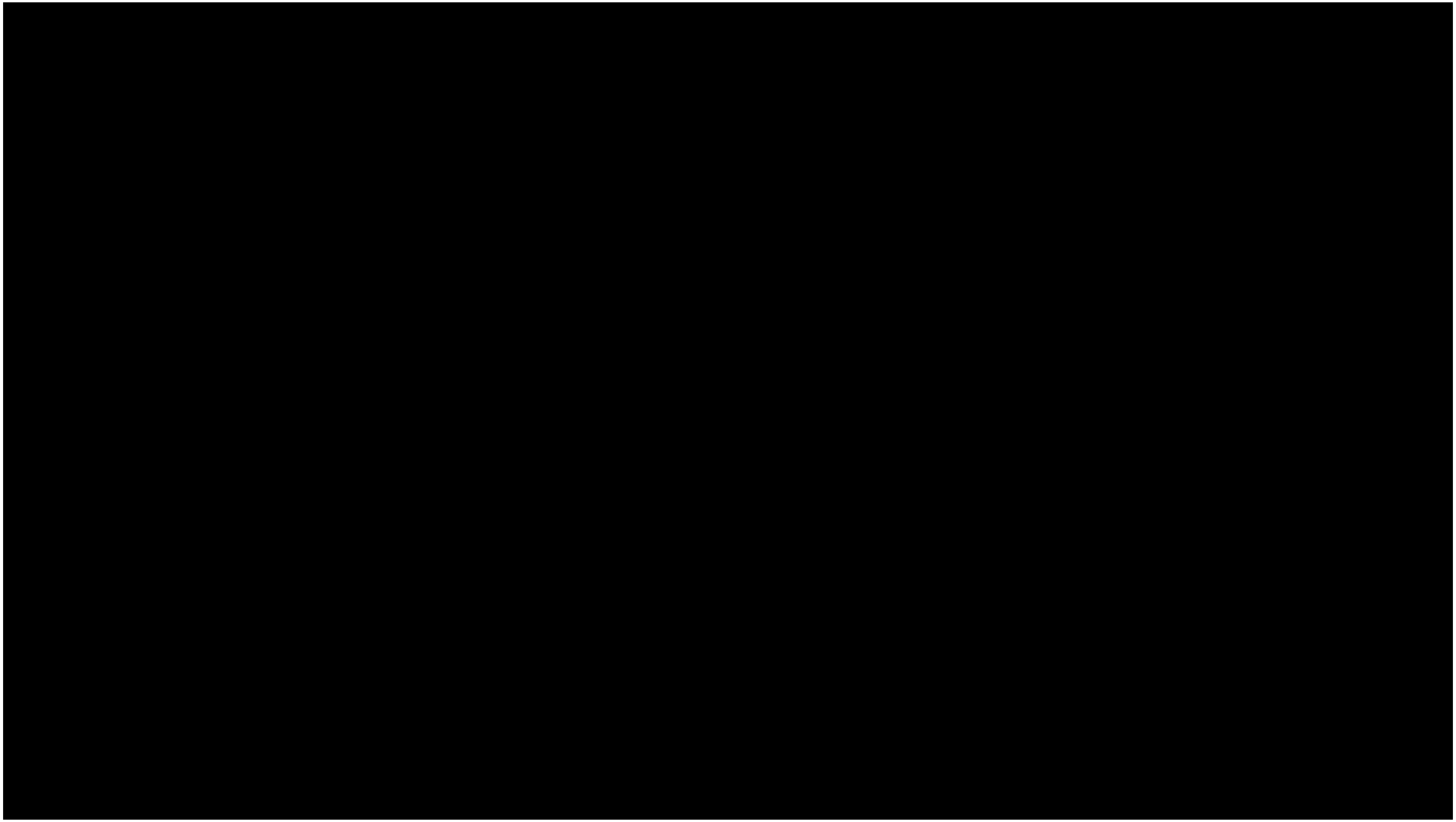




Specifying the scenario description

Visualizing the most recent overview image and the flight route

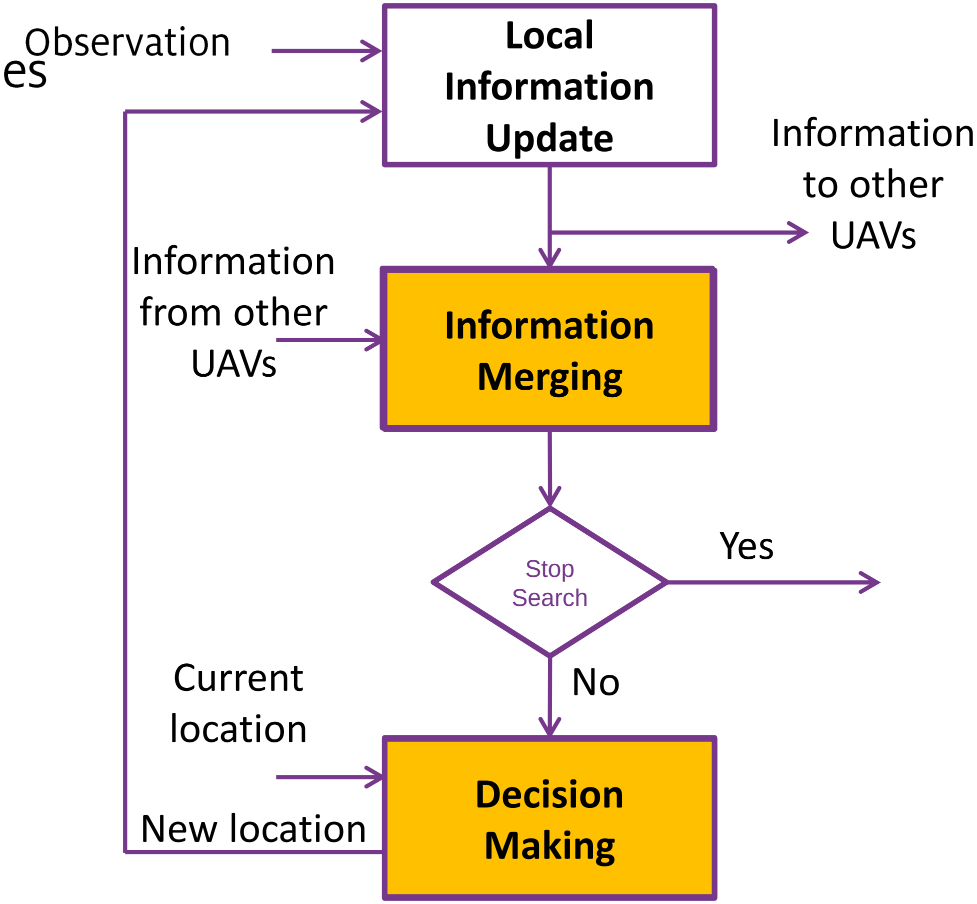
Demonstration Video



Cooperative Search

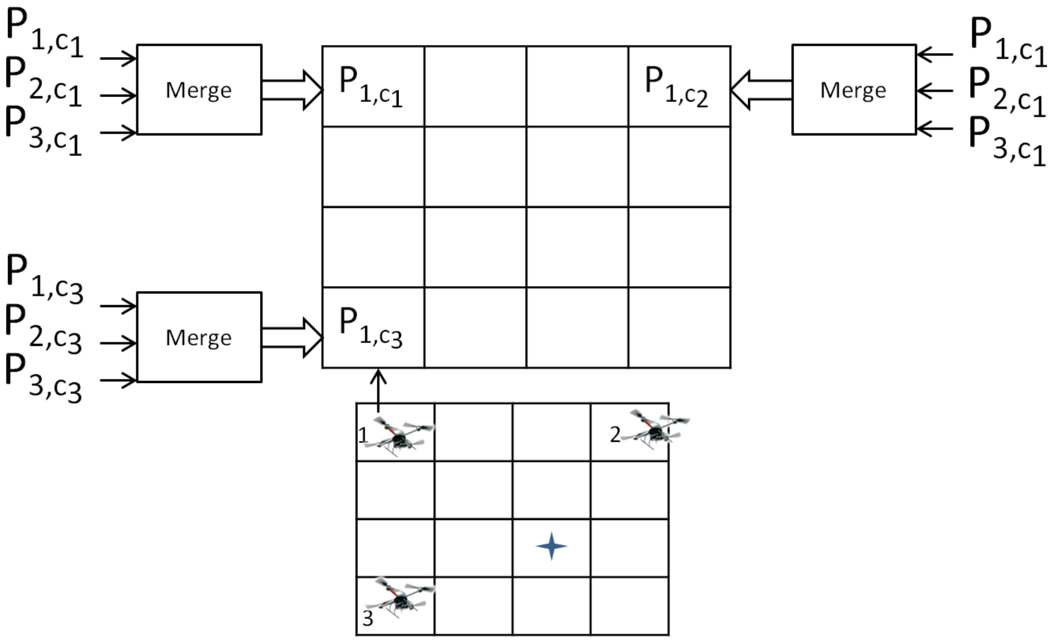
- Information merging
  - Grid of occupancy probabilities
  - How to merge grids?

- Decision making
  - Where to take observation?
  - Which path to follow?
  - How many observations?



Information Merging

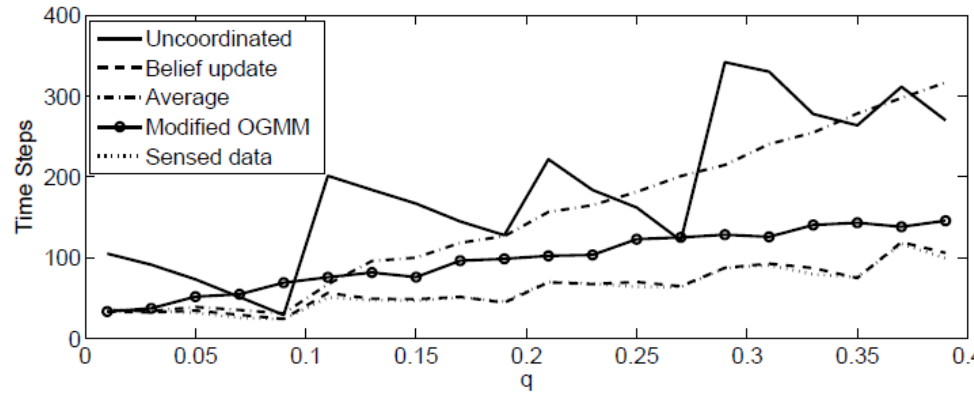
- Merging strategies
  - Belief update (replace information)
  - Average / consensus
  - Occupancy grid map merging
  - Sensed data sharing
- Assumptions
  - Stationary target
  - Predefined trajectory
  - Sensor model



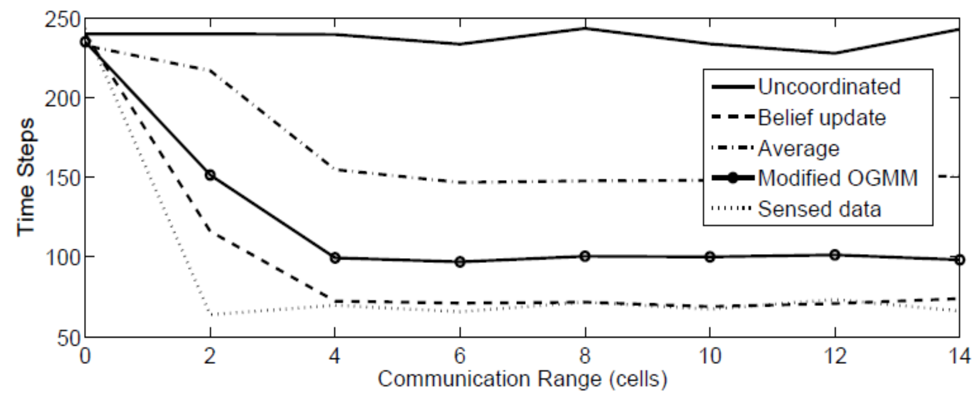
$P_{i,c}$: Information of UAV i at location c

Information Merging (2)

- Effect of sensor quality



- Effect of communication range

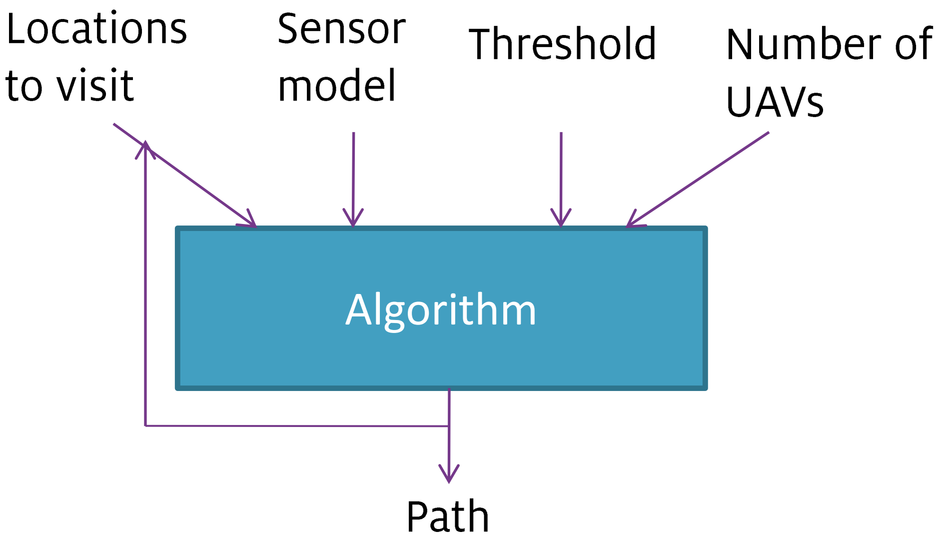


Search region = 10×10, 5 UAVs, random initial locations, **Threshold** = 0.99, p = 0.9,q = 0.2, target located at (6, 7)

Khan et al. Information Merging in Multi-UAV Cooperative Search, In Proc. ICRA June 2014.

Decision Making Algorithms

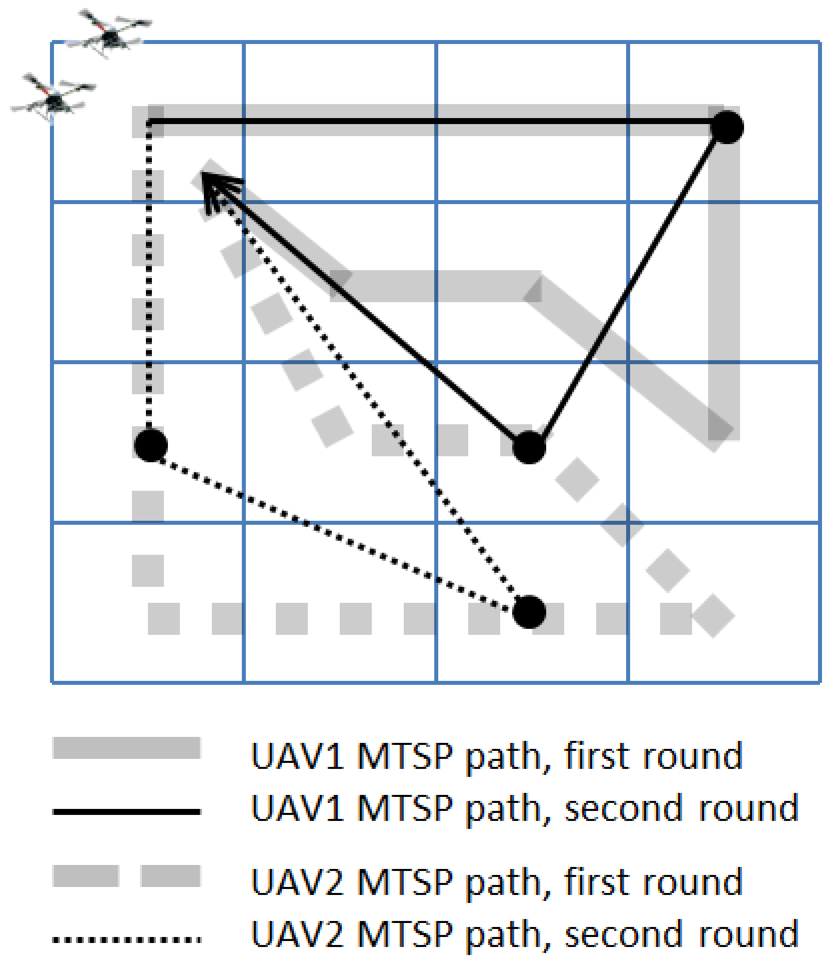
- Multiple Travelling Salesman Problem (MTSP) for route selection
- Number of observations required



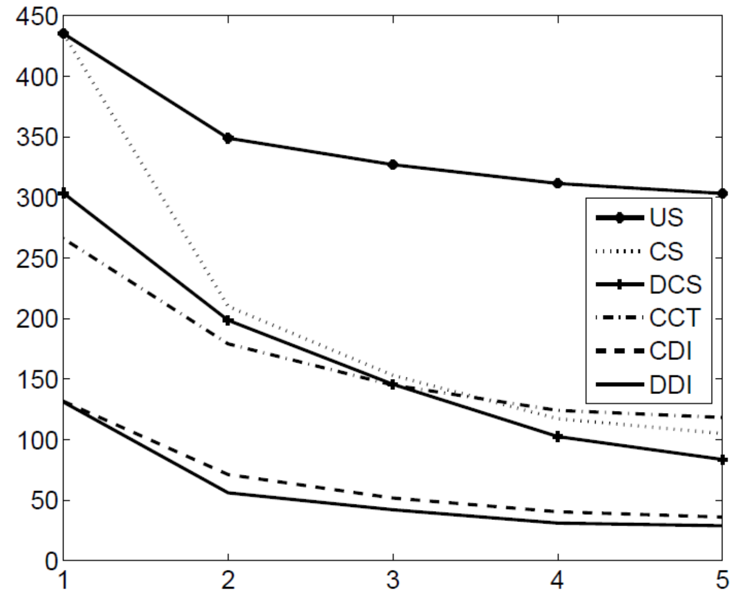
Decision Making Algorithms (2)

Information merging

	C	D
C	CCT	CDI
D	DCI	DDI



Comparison with State of Art



Targets = 1; p = 0.9; q = 0.2; Threshold = 0.99;
unlimitted communication.

Uncoordinated sweep search (US) [Choset_97_ICFSR]

Coordinated sweep search (CS)

Distributed cooperative search (DCS) [York_12_J Int Robot Sys]

Summary

- Joint research of four research groups at Klagenfurt University
- Successful demonstration at various training events
- Spin-off has been launched
- Follow-up research activities
- Presentations and media coverage

Acknowledgements

- cDrones Team @ AAU

Further Information

http://uav.aau.at