

Navigation and Control of Unmanned Aerial Vehicles in GPS-Denied Environments

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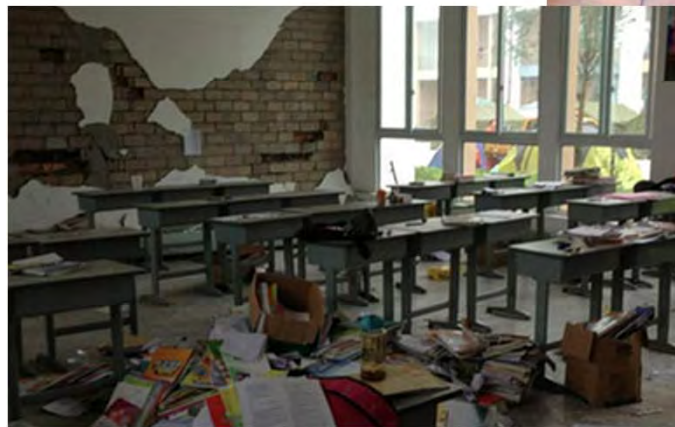
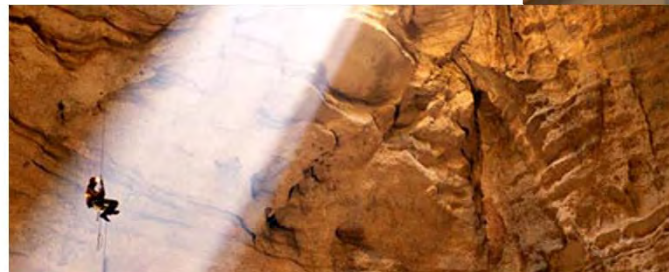
Outline of this talk...

- Introduction and motivations...
- Research highlights...
 - Navigation and control of UAVs in outdoor GPS-denied environments
 - GPS-less navigation and control of UAVs in indoor environments
 - Palm-size micro aerial vehicles
 - Vision-aided formation
 - UAV calligraphy
 - Vision-guided rotorcraft vertical replenishments
 - Unconventional UAV
- Ongoing projects...
 - International Micro Aerial Vehicle Competition 2014
 - GPS-less large-scale forest search
 - GPS-less urban canyon flight and perching
 - GPS-less landing on moving platforms
- Conclusion and acknowledgement...



Applications of UAVs in indoor environments

- Surveillance & patrolling
- Exploration & mapping
- Search & rescue
- Scout & reconnaissance



Introduction...

Motivations of the research...

Applications of UAVs in outdoor GPS-denied environments



- Searching
inside
forests



- Inspection
under
bridges



- Urban
canyon
navigation



Introduction...

The NUS Lion UAV Family



Introduction...

The NUS UAV Research Team



Team NUS² T-Lion

*The 2013 AVIC Cup
UAV Innovation
Grand Prix Team*



*The 2012 DARPA
UAVForge
Challenge Team
Team GremLion*



Introduction...

The NUS UAV Research Team



Team AeroLion



2014 International Micro Aerial Vehicle Competition



NUS UAV Research Group members

Navigation and control in GPS-denied environments

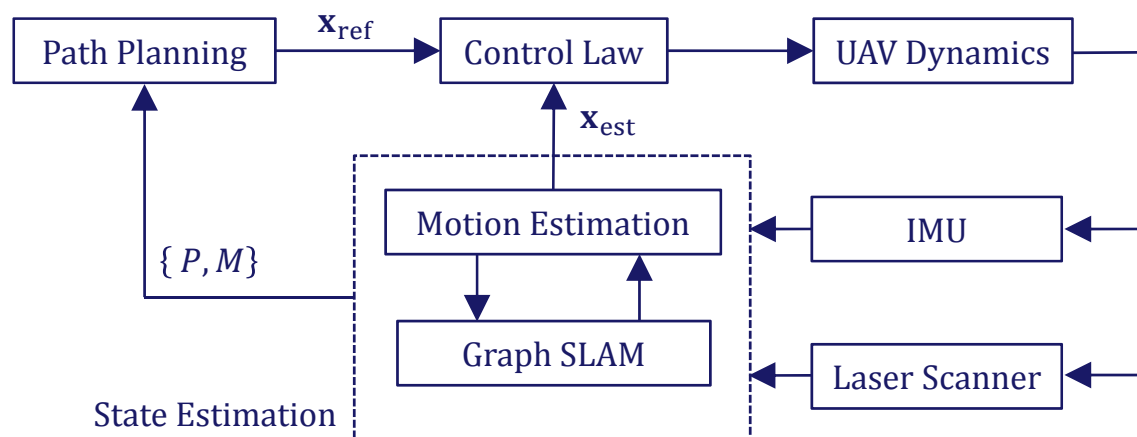
Objective: To develop a navigation system to explore theories and technologies that enable UAVs to realize autonomous navigation and control in cluttered environments, especially forest.

Graph SLAM Formulation

- Use a graph to present the problem
- Every node in the graph corresponds to a pose of the UAV during mapping
- Every edge between two nodes corresponds the spatial constraints between them



System Structure...



The goal of Graph SLAM is to find a configuration of the nodes that minimize the error introduced by the constraints

Research Highlights...

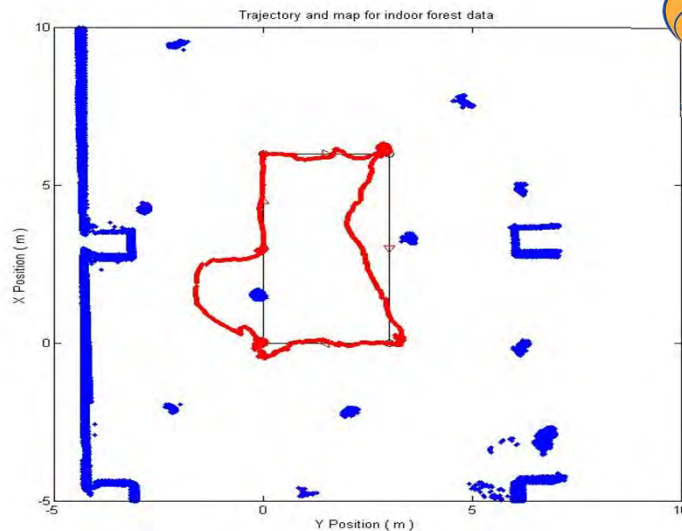
Navigation and control in GPS-denied forests

Q-LION

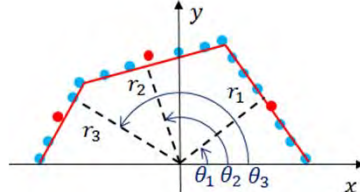
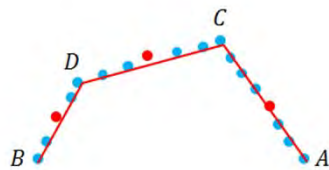
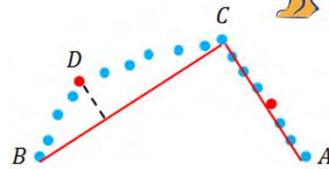
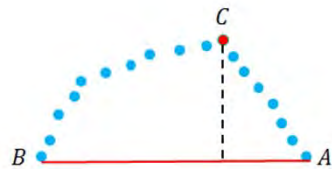


Platform specifications

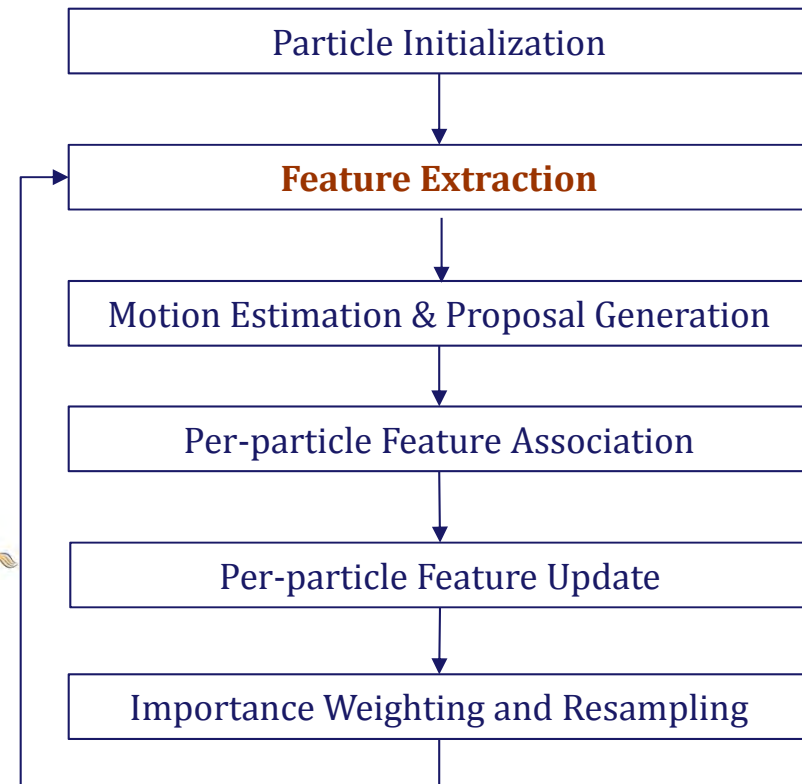
- Dimension: 0.8m×0.8m×0.4m
- Weight: 2.9 kg
- Flight endurance > 8 min
- Maximum speed > 6 m/s
- Fully autonomous indoor and outdoor with & without GPS



Objective: To develop a 3D indoor navigation system, which is able to aid UAVs to safely navigate through the unknown and complicated indoor environment and complete autonomously necessary flight missions.



FastSLAM



Feature Extraction – Point clustering via split-and-merge

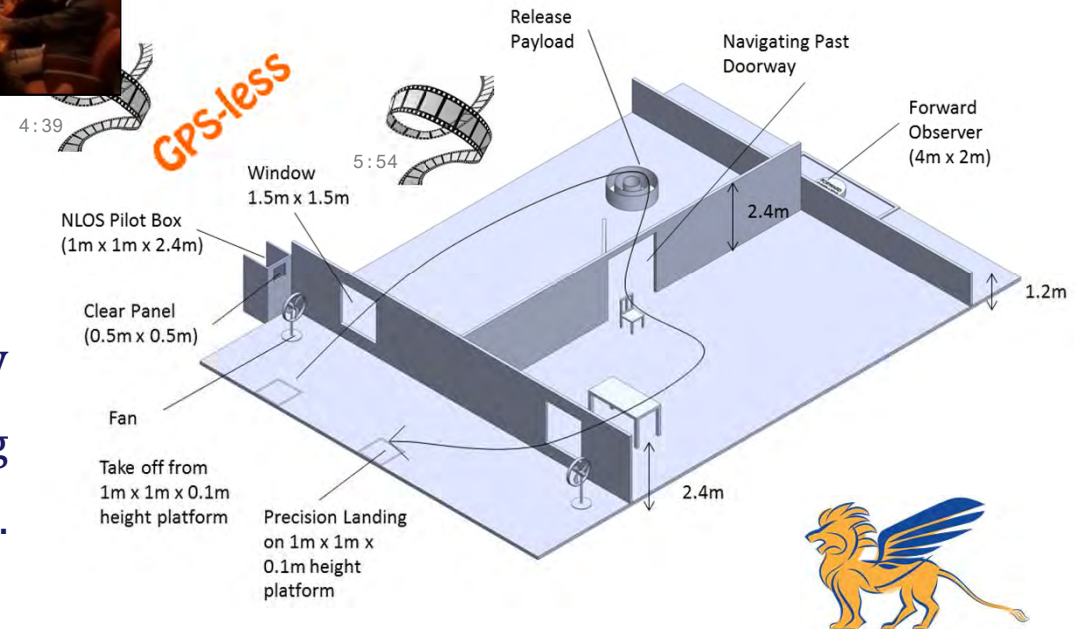
Research Highlights...

Indoor navigation and automatic flights



- Fully autonomous flight of a quadrotor UAV in a lecture theater during a final project presentation...

- Performance of the NUS UAV Team at Singapore Amazing Flying Machine Competition...



Research Highlights...

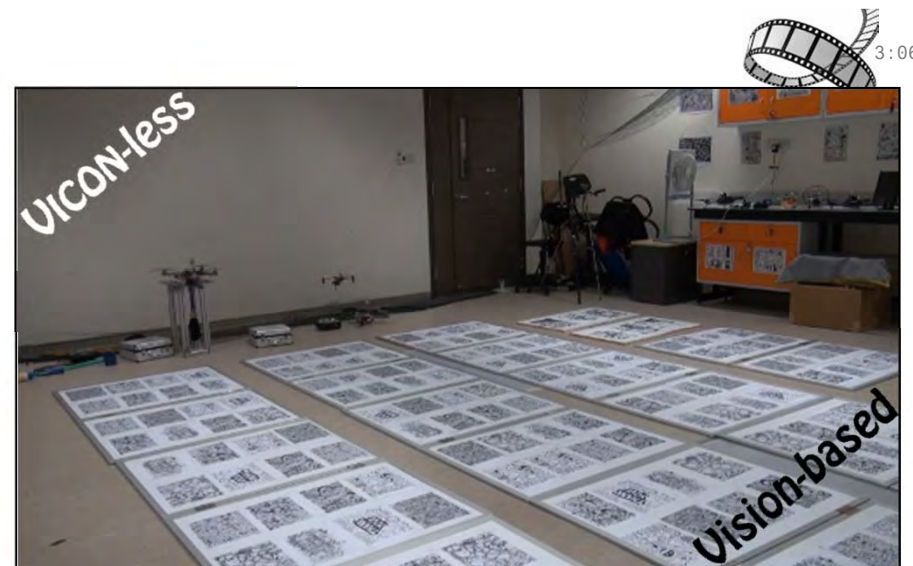
Fully autonomous micro aerial vehicles

We aim to develop an ultra compact micro aerial vehicle (MAV), which is able to safely navigate through indoor environment and complete autonomously necessary flight missions.

The MAV is tested in actual flights.

Specifications

- Largest dimension < 15 cm
- 40 grams including battery
- 8 minutes flight endurance
- VICON-based or vision-based fully autonomous

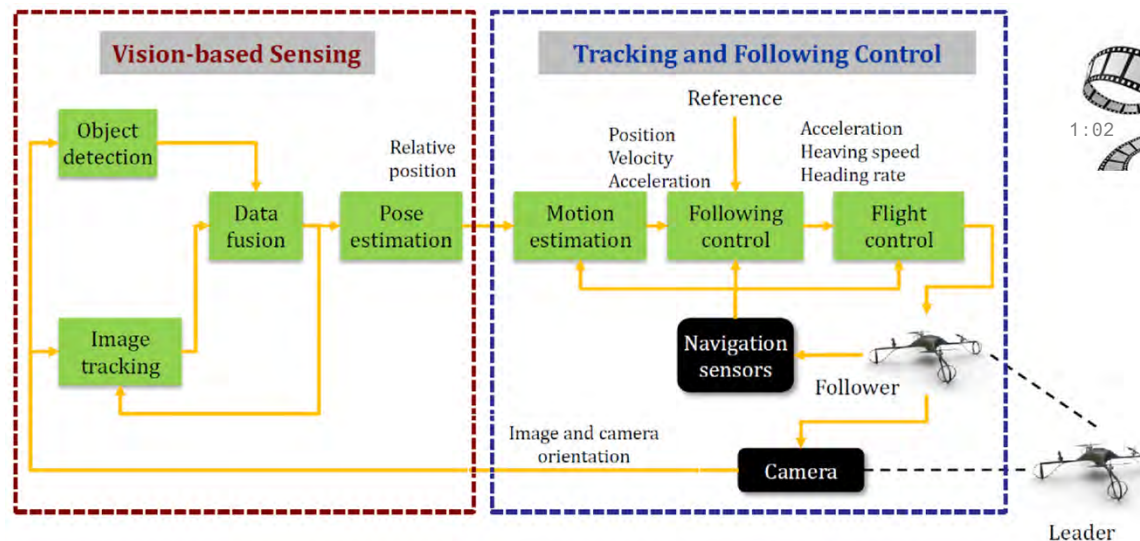


We aim to realize leader-follower formation using vision-aided sensing and motion estimation. Key features include:

- Vision-based displacement measurement
- Motion estimation
- Real-time onboard processing
- No inter-vehicle communication
- Robust following control

Vision-based sensing

- Object detection (geometry and shape)
- Image tracking (filtering and data association)
- Data fusion
- Pose estimation



Research Highlights...

Fun stuff – UAV calligraphy



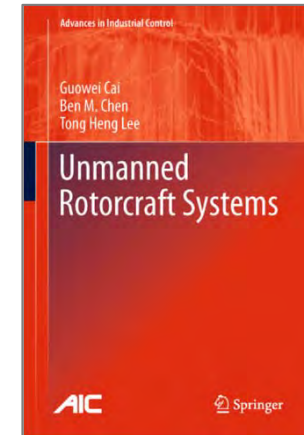
UAV calligraphy demonstration at Singapore Airshow 2014...

We explore the development of fully functional miniature unmanned helicopter systems. Research on identification and control of highly nonlinear model of the chopper, control and formation of multiple UAVs is thoroughly investigated.



Specifications

- Dimension: $1.4 \times 0.2 \times 0.5$ m
- Bare weight: 4.8 kg
- Payload: 5 kg
- Flight endurance > 30 min
- Max speed > 20 m/s



3:43



2:16

Research Highlights...

Vision-Guided Rotorcraft vertical replenishment

We have developed a real-time vision system for a UAV to transfer cargoes between two moving platforms for the Grand Prix. It requires a UAV to transfer four buckets one by one from one platform to the other. The UAV should also perform autonomous taking off, target searching, target following and landing. We had successfully completed the entire task, and were ranked first in the final round competition.



Research Highlights...

Vision-Guided Rotorcraft vertical replenishment

Key system features of the replenishment system...

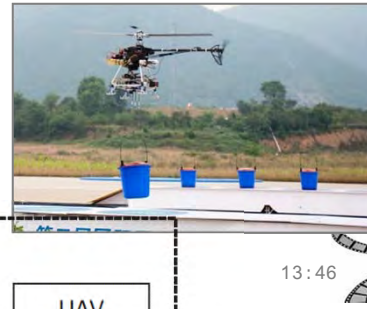
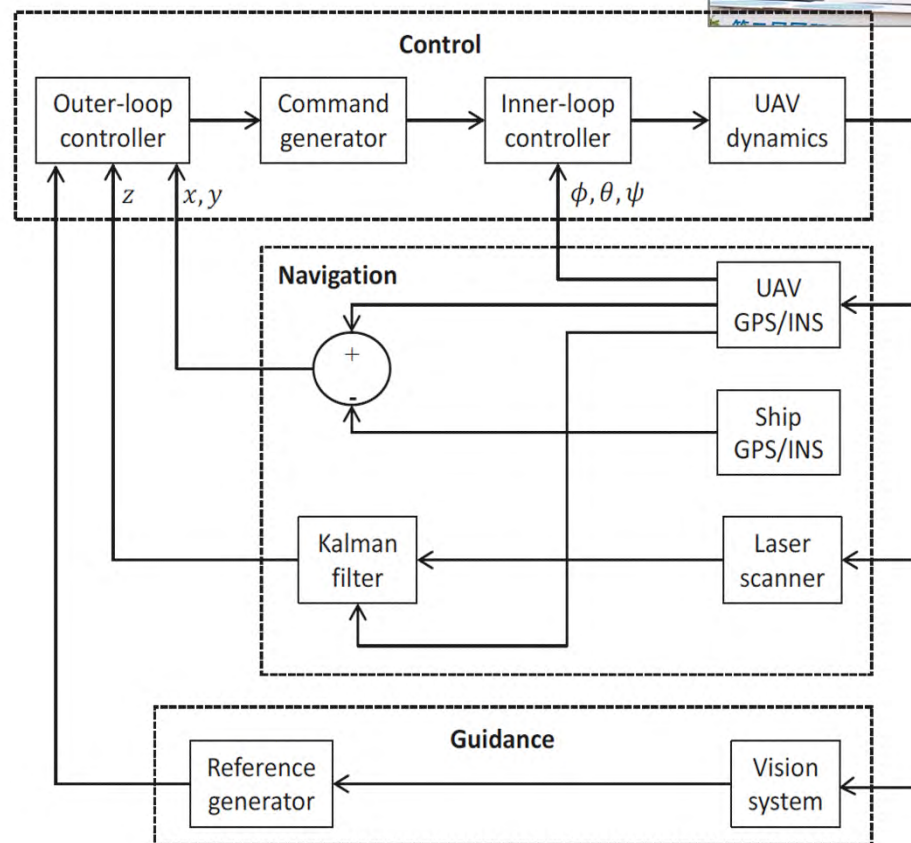
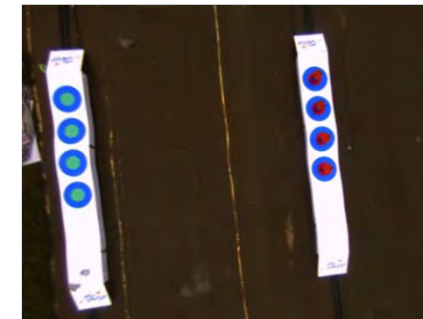
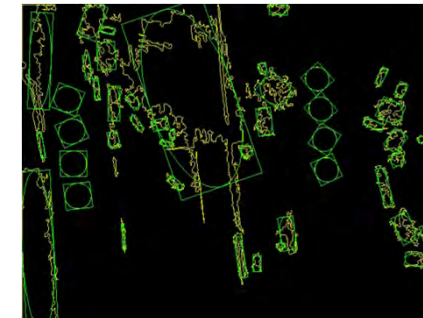


Illustration of vision detection...



color image

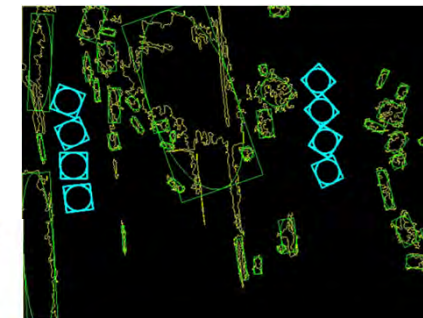
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③

④



final detection

⑤

System structure for guidance, navigation and control



Research Highlights...

Unconventional aircraft – Hybrid platforms

Gimballed Vector Thrust

- Roll and pitch controlled by gimbal system
- Yaw controlled by rotational speed difference

Gyro Stabilizer

- 5 gyros to stabilize 3-axis orientation
- Works on both hovering and cruising modes

Retractable Wings

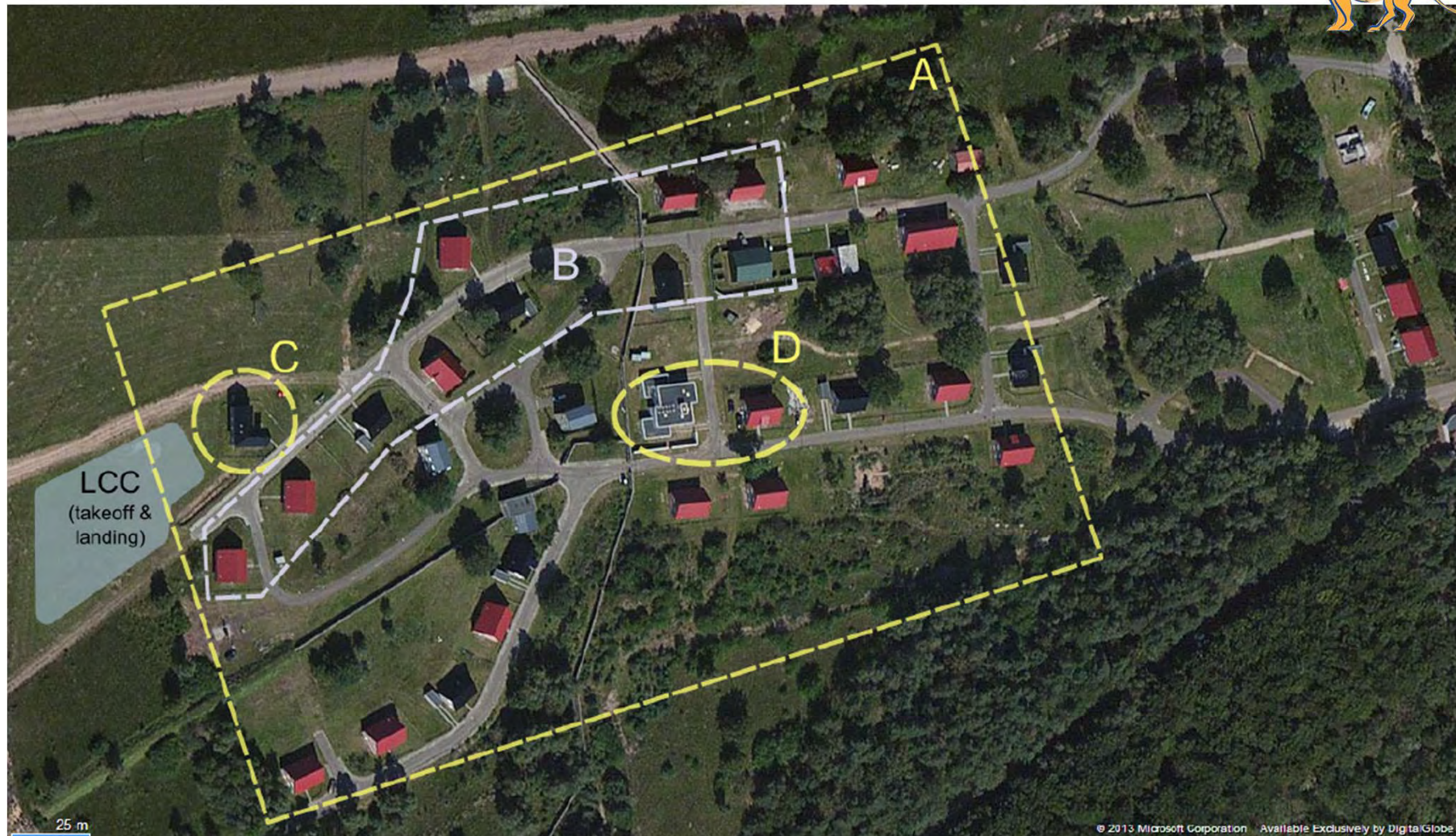
- 3 control modes available
- Enable VTOL, hovering, cruise flight



Ongoing Projects...

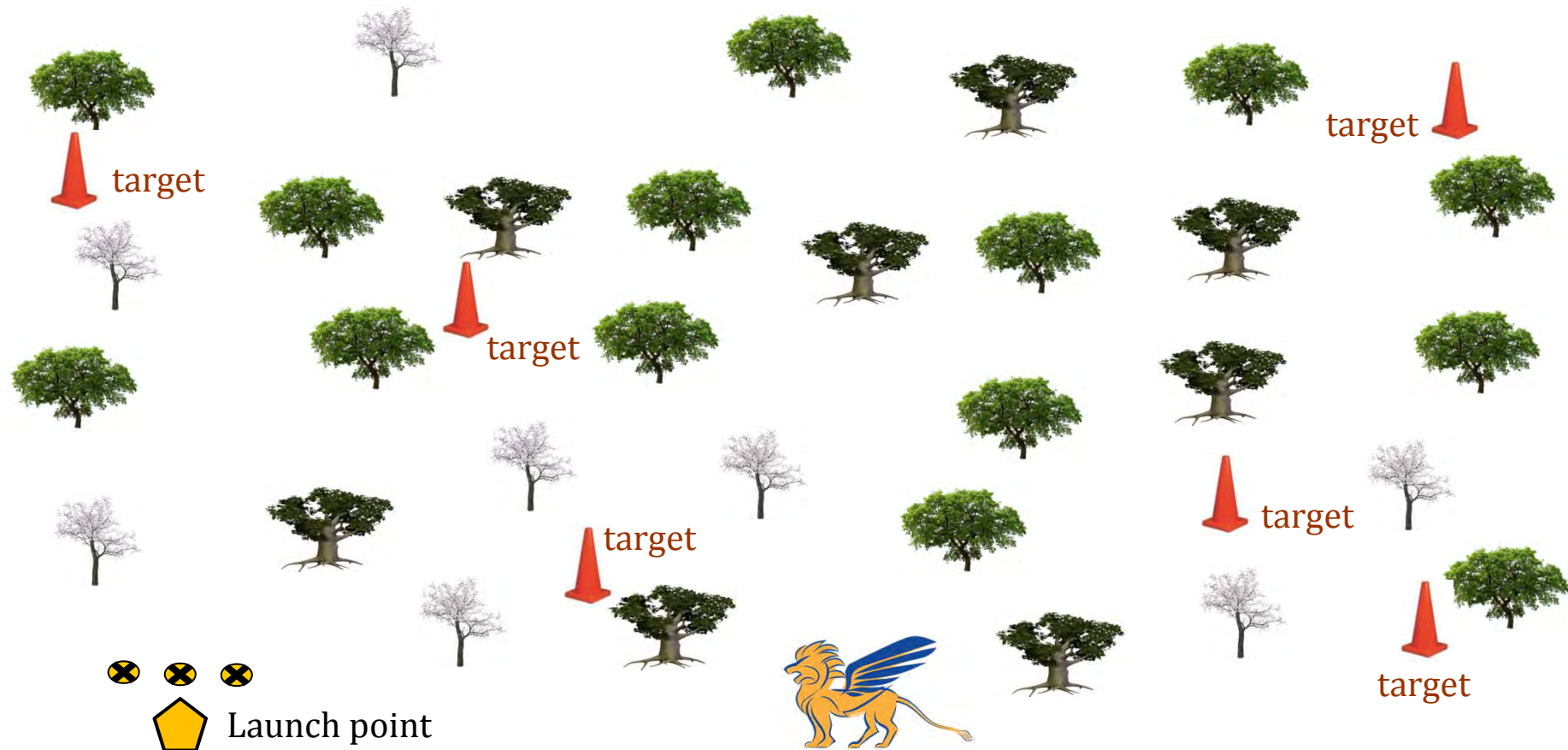
2014 International Micro Aerial Vehicles Competition

August 12–15, 2014, Delft, the Netherlands



Ongoing Projects...

Forest search (days and nights, GPS-less)



We aim to develop a fully autonomous system that enables UAVs to navigate thru and search inside a large-scaled unknown forest environment at day/night/dawn/dusk.

Ongoing Projects...

Urban canyon flight (days and nights, GPS-less)



We aim to automate the navigation of a UAV in urban canyons to avoid obstacles and reach a specified nearby destination via dead reckoning without a map of the area at day/night/dawn/dusk.

Ongoing Projects...

Automatic perching (days and nights, GPS-less)



We aim to navigate a UAV with Google Earth images in urban canyons and to search and identify an optimal spot for perching and at day/night/dawn/dusk.

Ongoing Projects...

Landing on moving platforms (days and nights, GPS-less)



We aim to develop technologies that are able to navigate a UAV to follow a moving platform (such as a ground vehicle or a ship) without GPS and to land on the platform.



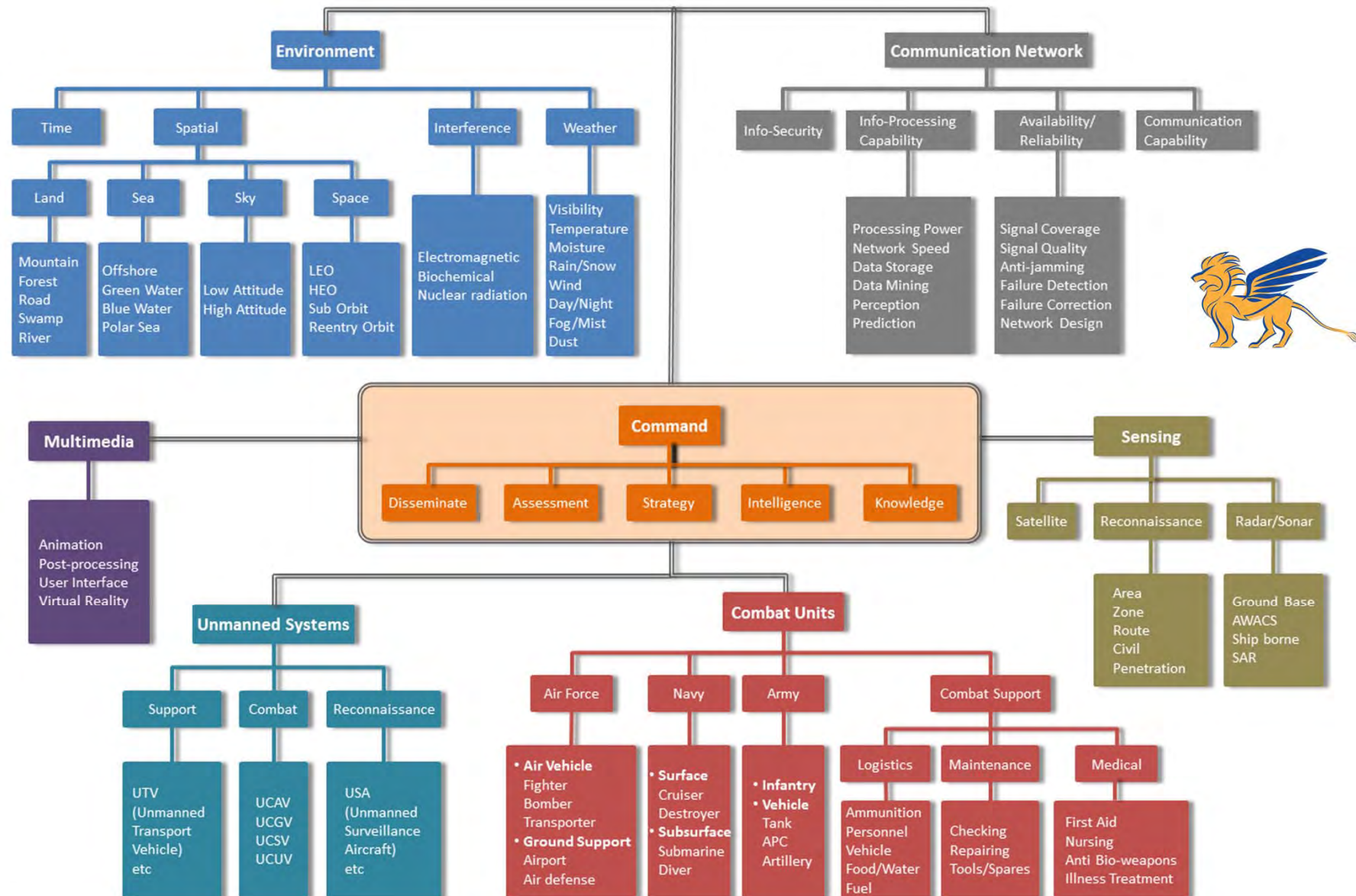
Here are some more ongoing projects, which NUS UAV Group and TL CSG is currently working on:

- Development of fully autonomous hybrid UAVs, which aims to achieve
 - Autonomous VTOL flight from small templates
 - Long flight endurance and range in fixed-wing mode
- Applications of micro unmanned vehicles in indoor and foliage environments
- Development of long endurance conventional UAVs...
-



Future Directions...

Integrated Unmanned Systems



Future Directions...

An illustration



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NUS ECE Unmanned Systems Research Group

Acknowledgment...

In memory of our deceased lions...



Crashed on 25 March 2006



Crashed on 14 May 2012

we pained, we learned, we gained...



Thank You!

Welcome to visit our group website at

<http://uav.ece.nus.edu.sg>

for more information on our research activities and published resources...