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

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Outline of this talk…

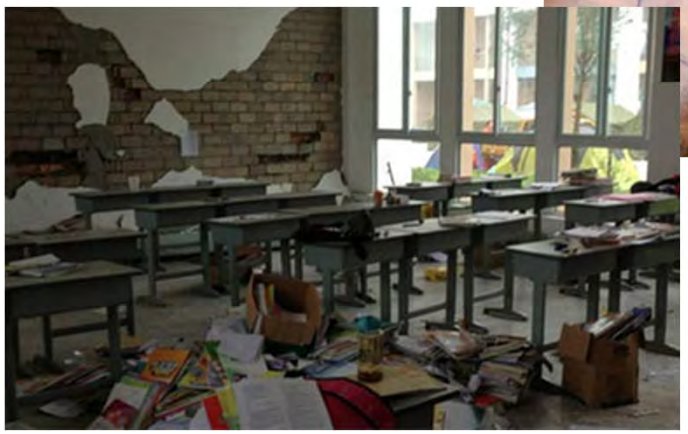
- Introduction and motivations…
- Research highlights…
  - Navigation and control of UAVs in outdoor GPS-denied environments
  - GPS-less navigation and control of UAVs in indoor environments
  - Palm-size micro aerial vehicles
  - Vision-aided formation
  - UAV calligraphy
  - Vision-guided rotorcraft 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…

Introduction…

Motivations of the research

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

NUS National University of Singapore

Team AeroLion

2014 International Micro Aerial Vehicle Competition

NUS UAV Research Group members

Research Highlights…

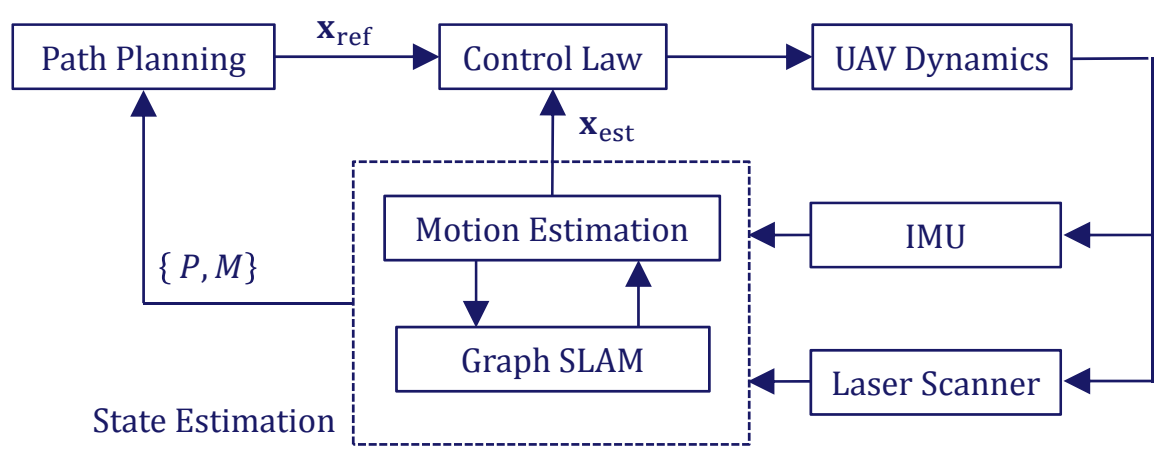
Navigation and control in GPS-denied environments

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…



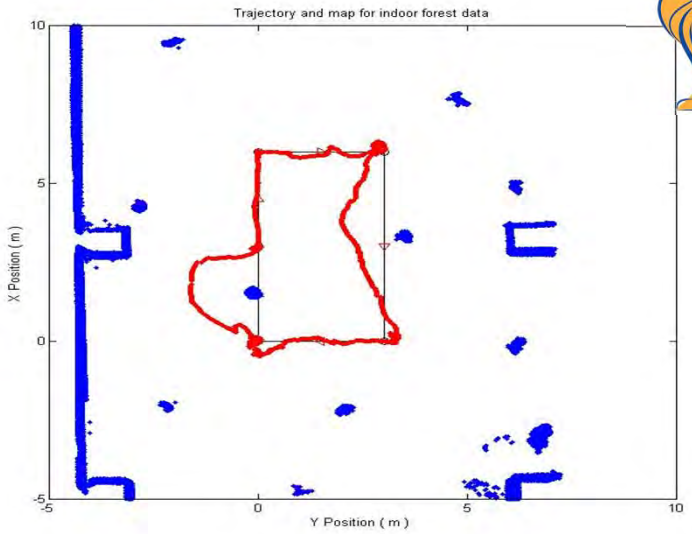
The goal of Graph SLAM is to find a configuration of the nodes that minimize the error introduced by the constraints

Research Highlights…

Navigation and control in GPS-denied forests

Platform specifications

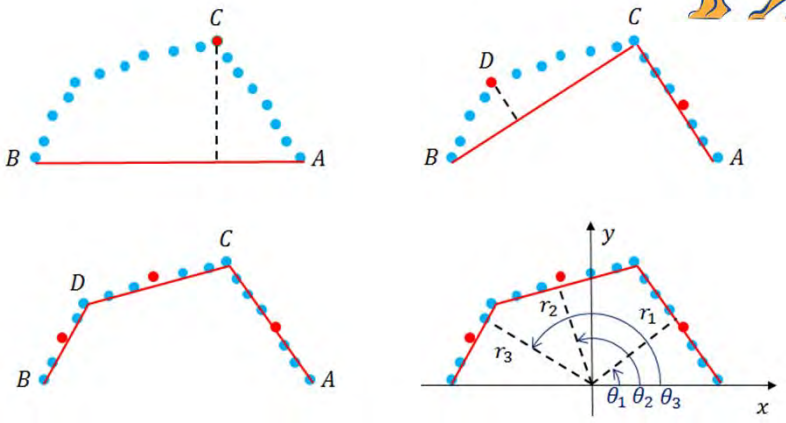
- Dimension: 0.8m×0.8m×0.4m
- Weight: 2.9 kg
- Flight endurance > 8 min
- Maximum speed > 6 m/s
- Fully autonomous indoor and outdoor with & without GPS



Research Highlights…

Indoor navigation and automatic flights

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

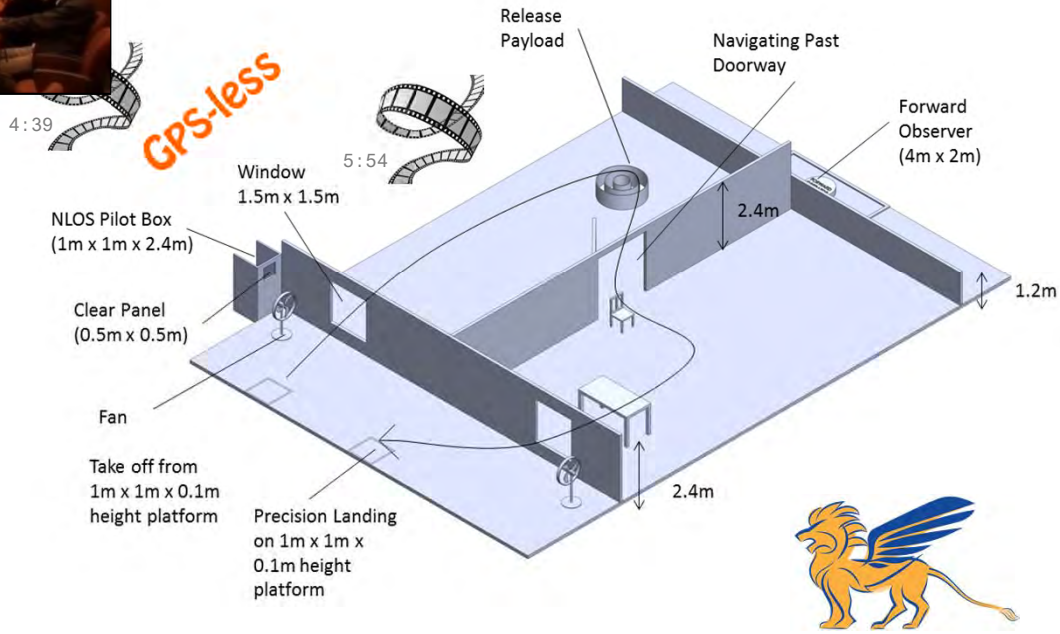
- Particle Initialization
- **Feature Extraction**
- Motion Estimation & Proposal Generation
- Per-particle Feature Association
- Per-particle Feature Update
- Importance Weighting and Resampling

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

Research Highlights…

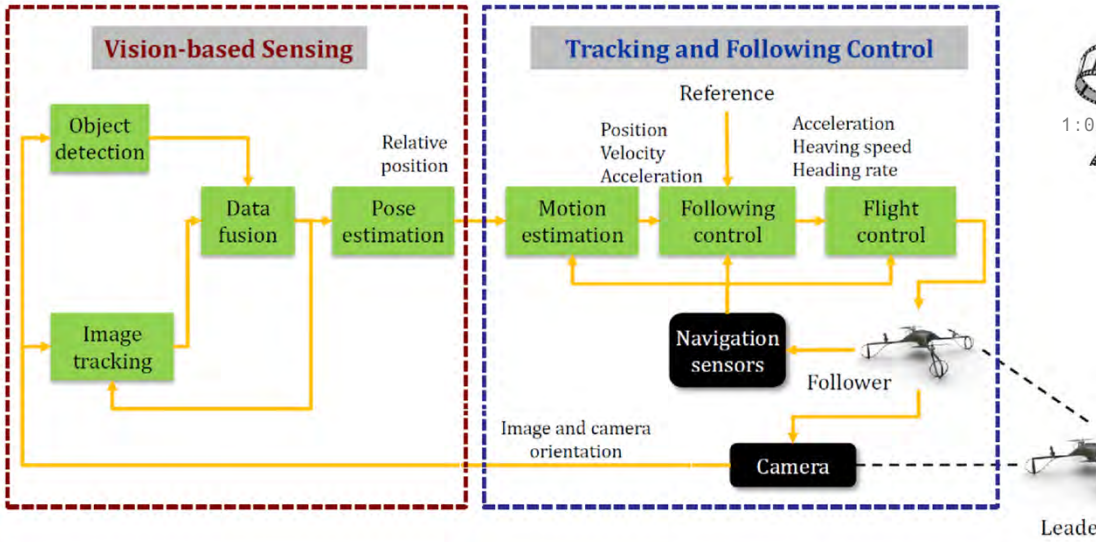
Vision-aided formation

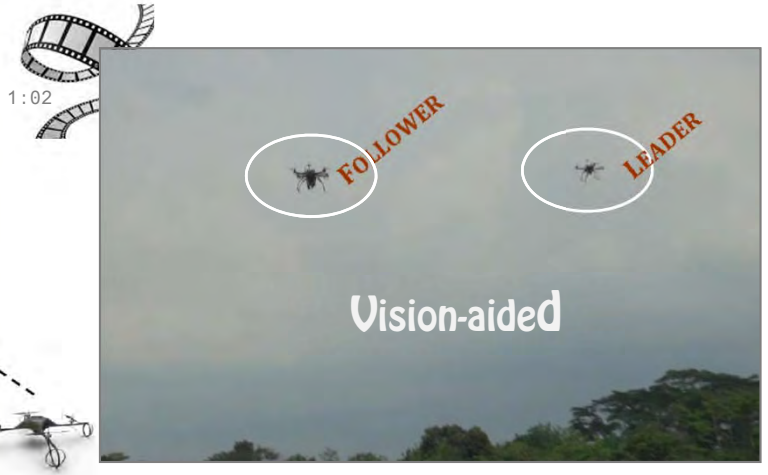
We aim to realize leader-follower formation using vision-aided sensing and motion estimation. Key features include:

- 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)
- Date fusion
- Pose estimation





Research Highlights…

Fun stuff – UAV calligraphy

UAV calligraphy demonstration at Singapore Airshow 2014…

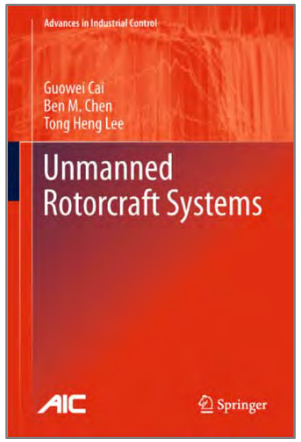
Research Highlights…

Unmanned helicopter systems

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



Research Highlights…

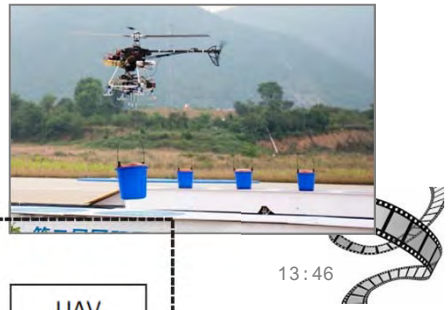
Vision-Guided Rotorcraft vertical replenishment

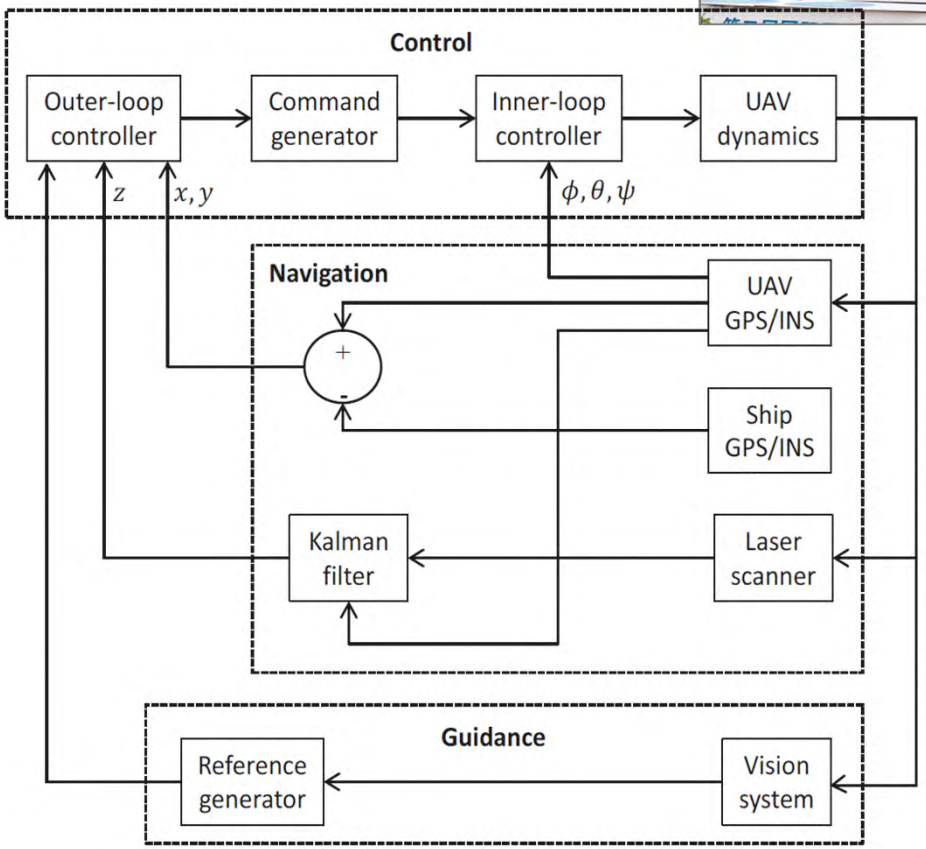
We have developed a real-time vision system for a UAV to transfer cargoes between two moving platforms for the Grand Prix. It requires a UAV to transfer four buckets one by one from one platform to the other. The UAV should also perform autonomous taking off, target searching, target following and landing.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

Vision-Guided Rotorcraft vertical replenishment

NUS National University of Singapore

Key system features of the replenishment system…



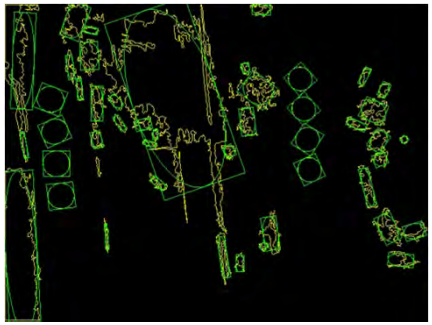


System structure for guidance, navigation and control

Illustration of vision detection…

color image

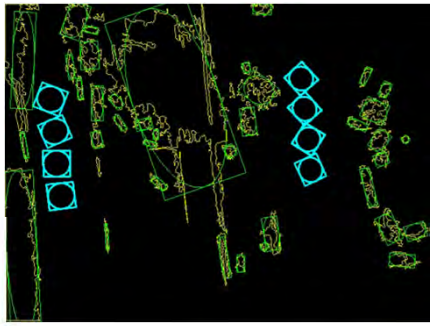
1



3

fitted ellipses

4



5

final detection

Research Highlights…

Unconventional aircraft – Hybrid platforms

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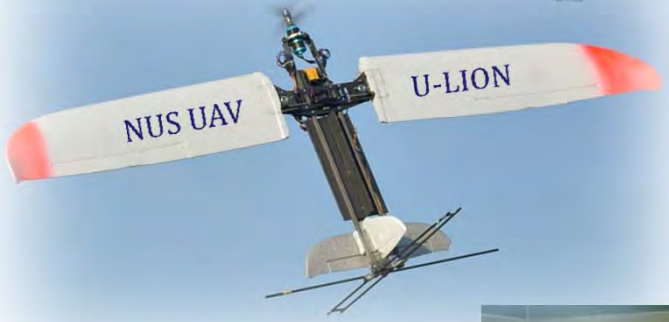
Gimballed Vector Thrust

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

Retractable Wings

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



Gyro Stabilizer

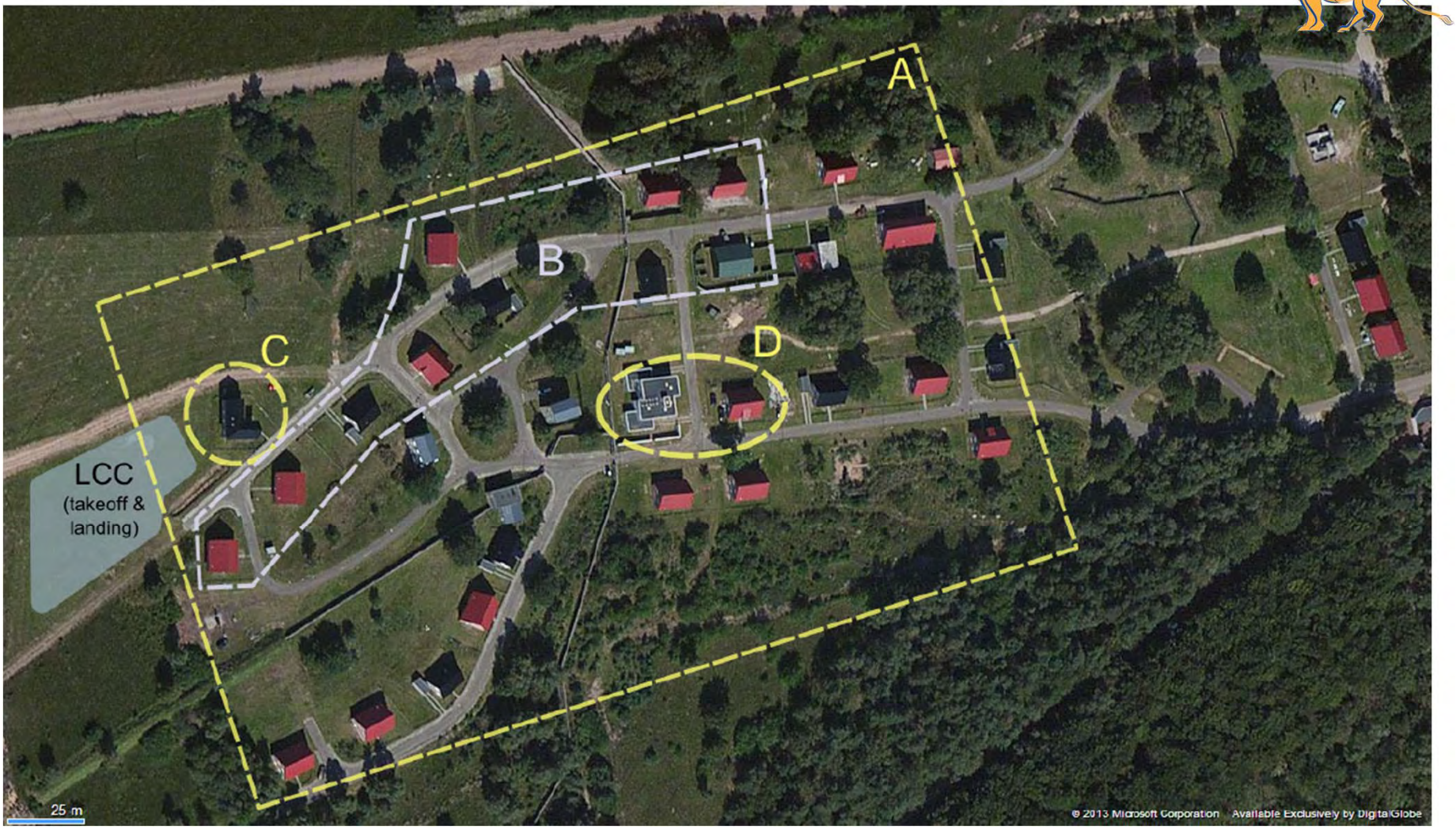
- 5 gyros to stabilize 3-axis orientation
- Works on both hovering and cruising modes

Ongoing Projects…

2014 International Micro Aerial Vehicles Competition

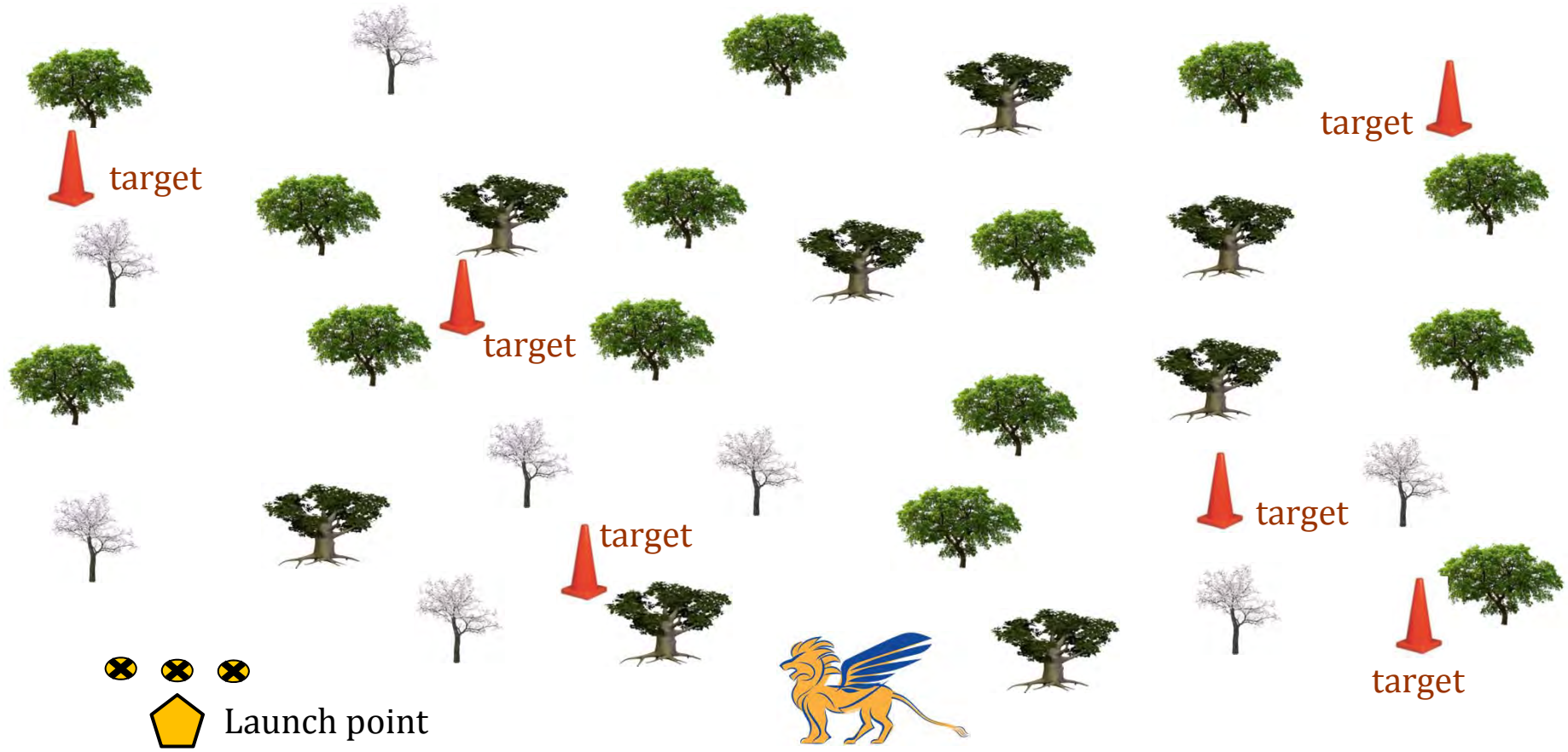
NUS National University of Singapore

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)

2D occupancy grid map

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.

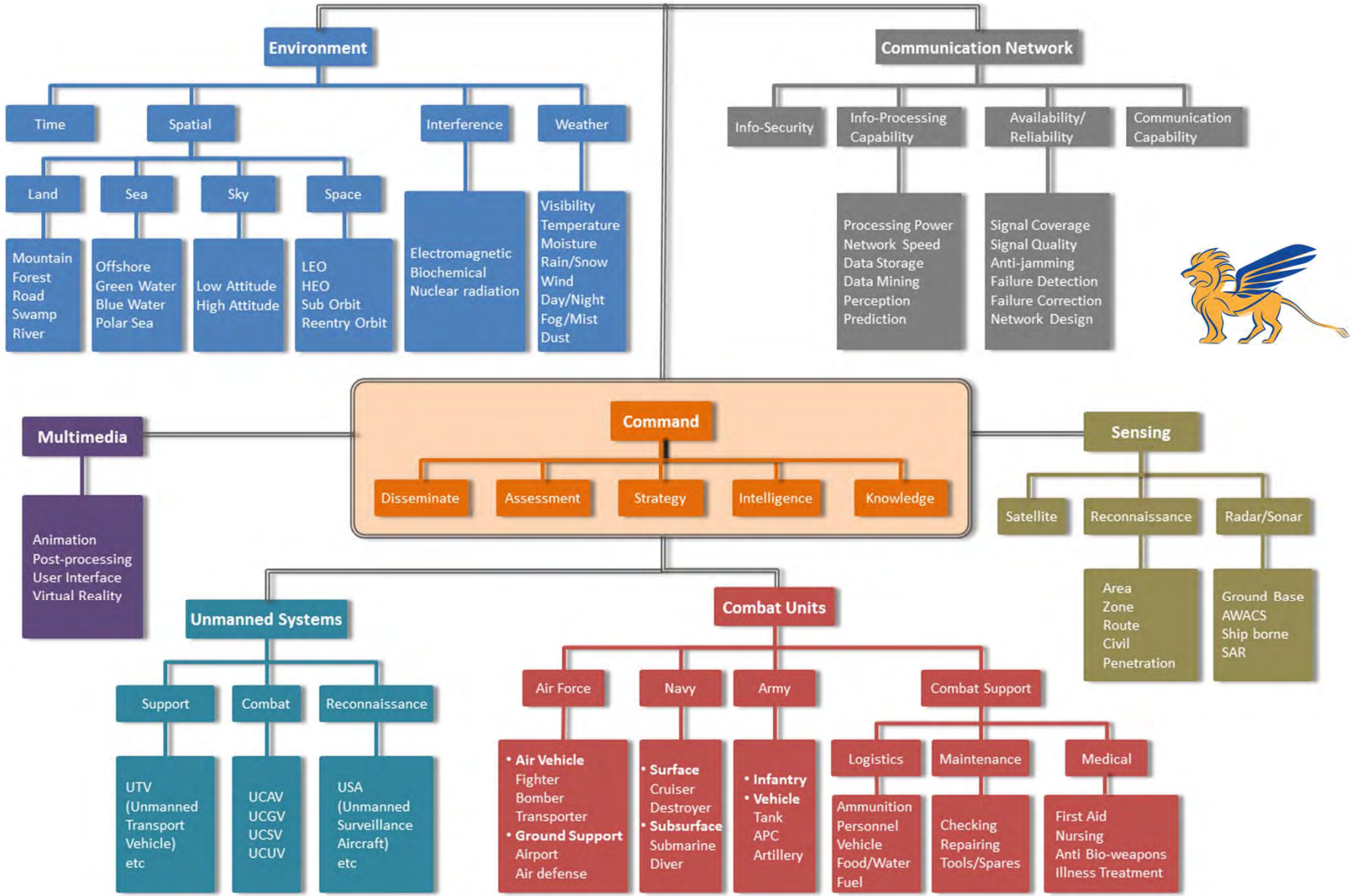
Ongoing Projects…

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

Acknowledgment…

Special thanks to the support from…

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Temasek Laboratories

National University of Singapore

Acknowledgment…

Special thanks to the members of my research team…

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Zhao Shiyu, Wang Biao, Cai Guowei, Tong H Lee

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…

NUS National University of Singapore

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…