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

- HeLion
- K-Lion
- Q-Lion
- U-Lion
Introduction...

The NUS UAV Research Team

Team NUS-T-Lion

The 2013 AVIC Cup
UAV Innovation
Grand Prix Team

Team GremLion

The 2012 DARPA
UAVForge
Challenge Team
Introduction...

The NUS UAV Research Team

Team AeroLion

2014 International Micro Aerial Vehicle Competition
**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

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

Forest Navigation
**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**

1. Particle Initialization
2. **Feature Extraction**
3. Motion Estimation & Proposal Generation
4. Per-particle Feature Association
5. Per-particle Feature Update
6. 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
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
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.
Key system features of the replenishment system...

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

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

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.
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.
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

Environment
- Time
  - Land
  - Mountain
  - Forest
  - Road
  - Swamp
- Spatial
  - Sea
  - Offshore
  - Green Water
  - Blue Water
- High Attitude
  - Low Altitude
- Space
  - LEO
  - HEO
  - Sub Orbit
  - Reentry Orbit
- Electromagnetic
- Biochemical
- Nuclear radiation
- Interference
- Weather
  - Visibility
  - Temperature
  - Moisture
  - Rain/Snow
  - Wind
  - Day/Night
  - Fog/Mist
  - Dust

Communication Network
- Info-Security
- Info-Processing Capability
- Availability/Reliability
- Communication Capability
- Processing Power
- Network Speed
- Data Storage
- Data Mining
- Perception
- Prediction
- Signal Coverage
- Signal Quality
- Anti-Jamming
- Failure Detection
- Failure Correction
- Network Design

Multimedia
- Animation
- Post-processing
- User Interface
- Virtual Reality

Unmanned Systems
- Support
- Combat
- Reconnaissance
- UTV (Unmanned Transport Vehicle) etc
- UCAS/LCGV/UCS/V/UCUV
- USA (Unmanned Surveillance Aircraft) etc

Command
- Disseminate
- Assessment
- Strategy
- Intelligence
- Knowledge

Combat Units
- Air Force
  - Air Vehicle
  - Fighter
  - Bomber
  - Transporter
  - Ground Support
  - Airport
  - Air defense
- Navy
  - Surface
  - Cruiser
  - Destroyer
  - Subsurface
  - Submarine
- Army
  - Infantry
  - Vehicle
  - Tank
  - APC
  - Artillery
- Logistics
- Maintenance
- Medical
- Checking
- Repairing
- Tools/Spare
- First Aid
- Nursing
- Anti Bio-Weapons
- Illness Treatment

Sensing
- Satellite
- Reconnaissance
- Radar/Sonar
- Area
- Zone
- Route
- Civil
- Penetration
- AWACS
- Ship borne
- SASS

Unmanned Aerial Systems ~ 25
Future Directions...

An illustration
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NUS ECE Unmanned Systems Research Group
In memory of our deceased lions...

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...