

Managing Separation of Unmanned Aerial Vehicles Using High-Integrity GNSS Navigation

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Outline



- Unmanned Aerial Vehicle (UAV) Networks
 - Applications
 - Ground-driven architecture
 - Local-Area Differential GNSS (DGNSS) Navigation
- Concept of Operations
- Risk Model for Safe Separation
- Error Model for Safe Separation
- Future Work: KAIST flight testing

UAV Applications (1): Scientific Observations, Photography



Ice Monitoring in Arctic

Volcanic Ash Monitoring



Source: A. Armstrong, NOAA (New York Times, Oct. 2007)

Source: (concept) G. Gao, (picture) H. Thorburn, Wikimedia Commons, 2010

UAV Applications (2): Reconnaissance, Surveillance



White Sands **Missile Range, NM**



Source: USGS/ Wikimedia Commons

> Source: **Google Maps**

Boeing/Paine Field, WA



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UAV Applications (3): *Reconnaissance, Surveillance*



Inwood and nearby (gated) subdivisions, San Antonio, TX



Source: Google Maps

Concerns over Threat to Privacy



Source: TIME Magazine (cover), 11 February 2013.



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Constraints of Commercial UAV Network Environment



- Service must be cost-effective
- UAV design and flight operations dominate achievable performance
 - Low-power/weight/cost receiver chipsets
 - Airborne dynamics are larger than for manned aircraft.
 - Flying (relatively) close to ground objects → significant airborne multipath from ground reflections
- Two-way datalink required for guidance
 - Monitoring separation is a key responsibility of the ground controller

Local-Area UAV Network Concept





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Separation for UAV Networks using GNSS

Simplification of GBAS for UAV Networks

• See: S. Pullen, *et al,* "LADGNSS Architectures Optimized to Support UAVs" *ION ITM 2013*, San Diego, CA, Jan. 2013





Safe Separation: Definitions of Terms



- "In-network" UAVs: UAVs in the same network
 - Share the same source of guidance
 - Share the same LADGNSS differential corrections
- "Out-of-network UAVs": all other UAVs
 - May share use of GNSS, but do not share guidance or differential corrections
 - Fly in the same general airspace allocated to UAVs
- "Manned aircraft": aircraft with human occupants
 - Assumed to fly in their own airspace (separate from UAVs)
- "Ground obstructions": the ground and any people, buildings, etc. attached to the ground

Components of Separation Budget





Altitude Limit or Other Vehicle ("Target")

Risk Model for Total Separation (example numbers for suburban applications)







Solve for Pr(SV) to meet total safety requirement:

Pr(HH | SV) × Pr(SV) ≤ 10⁻⁹ ← Target level of safety

Scenario	Pr(SV) (mean)	Pr(SV) (worst case)
In-network UAV	1.0	10 ⁻⁴
Out-of-network UAV	1.0	10 ⁻⁵
Upper limit (manned a/c)	1.0	10 ⁻⁷
Lower limit (ground)	0.01	10 ⁻⁶

Preliminary Error Budget (3-D separation between in-network UAVs)





Preliminary Error Budget (vertical separation from manned aircraft)



Error Source	Bounding Sigma (meters)	
User navigation	1.5	
User path-following	2.0	
User guidance	1.0	
Target navigation	3.0	
Target path-following	4.0	
Target guidance	N/A	potentially correlated, but assumed
RSS	5.7	independent

Out of Network UAVs: "Sense and Avoid"



- Safe separation from out-of-network UAVs requires some form of "sense and avoid" technology.
- *Most practical solution*: requirement for UAVs to broadcast position information at regular intervals
 - "ADS-B-OUT" for UAVs, but with much simpler, miniaturized components.
 - Report aircraft type, position, velocity, and source of navigation (e.g., a variation of GNSS)
 - "ADS-B-IN" function may be delegated to ground controller for short-range systems
- Guidance adaptation to out-of-network UAVs, particularly "non-friendly" ones, is a major challenge.

Future Work: KAIST Experiments



- Test elements of UAV network architecture with flying airborne vehicles.
- Utilize "IMT" GBAS prototype developed by Prof. Jiyun Lee at KAIST (Daejeon, Korea) along with existing commercial DGPS system.
- Key test objectives:
 - Examine receiver performance of existing UAVs in different environments (using static "pseudo-user" as control).
 - Evaluate correlated errors of UAVs close to each other.
 - Map resulting UAV error models to separation standards proposed here.

GBAS IMT Reference Receivers at KAIST







Vicinity of KAIST GBAS



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Summary



- A concept for autonomous UAV networks supported by local-area DGNSS has been proposed.
 - Medium-range photography / data-collection
 - Short-to-medium reconnaissance / surveillance
- A model for separation standards between networked UAVs and obstacles/other aircraft (including other aircraft) has been developed.
 - Based on risk and consequences of potential UAV collisions
- Flight tests to come using KAIST GBAS prototype.
 - Identify UAV navigation and flight technical errors under various conditions.

Ending

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Questions are welcome!

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Backup Slides follow...



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GBAS Architecture Overview (supports CAT I Precision Approach)





LGF Ref/Mon Receivers and Processing

