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Navigating without a Navigator

A Review of Positioning and Navigation Technologies for UAVs

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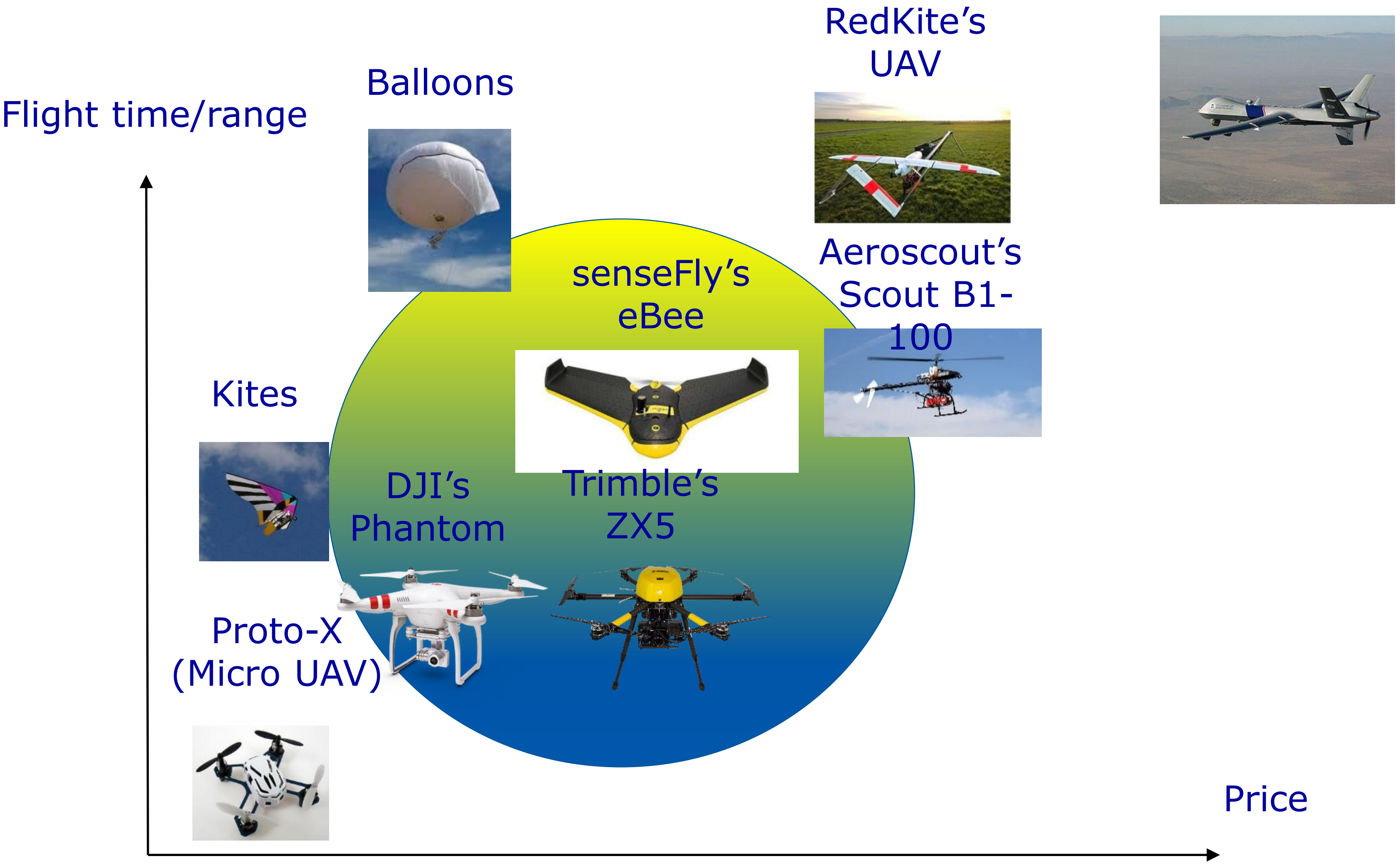
UAV Platforms



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The Ohio State University

Comparison of UAV Platforms

Three types: Fixed-Wing, Rotary-Wing, Multi-Rotor
…. and also Transformational Hybrids

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THE OHIO STATE UNIVERSITY
Partial Credit: Clive Fraser

Positioning and Navigation for UAVs

Positioning

- Navigation = positioning + guidance
- Positioning of other payloads and sensors
- Geo-referencing
- Real-time or post-processed

Navigation

- En-route to / from ‘survey’ location
- Guidance, autopilot, control
- Geo-fencing, controlled airspace, etc.
- Emergency recovery
- Real-time

Requirements

- Remotely piloted (RPAS), BVLOS operations, autonomous?
- Different levels of accuracy and integrity are required (RNP?)
- But, often combined into a single integrated payload

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UAV Positioning Sensors

Absolute Positioning

- Low or modest temporal resolution
- Single-frequency, code-based GNSS (common), DGPS
- Multi-Constellation, Multi-Frequency GNSS RTK & PPP
- Pressure sensor (height, airspeed)
- Visual-based, cameras, video
- Radar, Altimeter, Lidar
- Feature Matching, Terrain Referenced Navigation, SLAM
- Cooperative positioning, Swarming

Relative Positioning

- High temporal resolution
- Altitude Heading Reference System (AHRS): accelerometer, gyro, magnetometer
- Roll, pitch, yaw angles, and velocities/positions estimated
- Vehicle Dynamics Modelling

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Typical UAV GNSS Receivers

Single-Frequency GPS (autopilot systems)	u-blox LEA-6H
No raw data	
No timing	
Horizontal position accuracy (without aiding)	2.5 m
Time accuracy	30 ns
Power requirements	121 mW

Dual-Frequency GPS	NovAtel OEM615
Event input in	Yes
PPS out	Yes
Single Point L1 RMS	1.5 m
Single Point L1/L2 RMS	1.2 m
Time accuracy	20 ns
Power requirements	1 W

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GNSS Limitations and Trade-offs

RTK

- Requires base station and radio-link setup
- Network RTK requires access to mobile signal (GSM, 3G,4G). This may be difficult in remote or offshore area

PPP

- No base station required
- Requires an initialisation time of about 20 minutes to provide dm to cm accuracy.
- In addition link to external data source required

GBAS

- Availability localised to areas in the vicinity of airports
- GBAS can be set up and installed around assets of interest, but at significant cost

SBAS

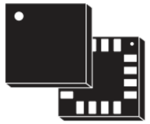
- Requires line of site to SBAS (e.g. EGNOS) satellite
- Low elevation at high latitudes - signal disruptions
- Internet-based access, EDAS

Inertial Navigation Systems

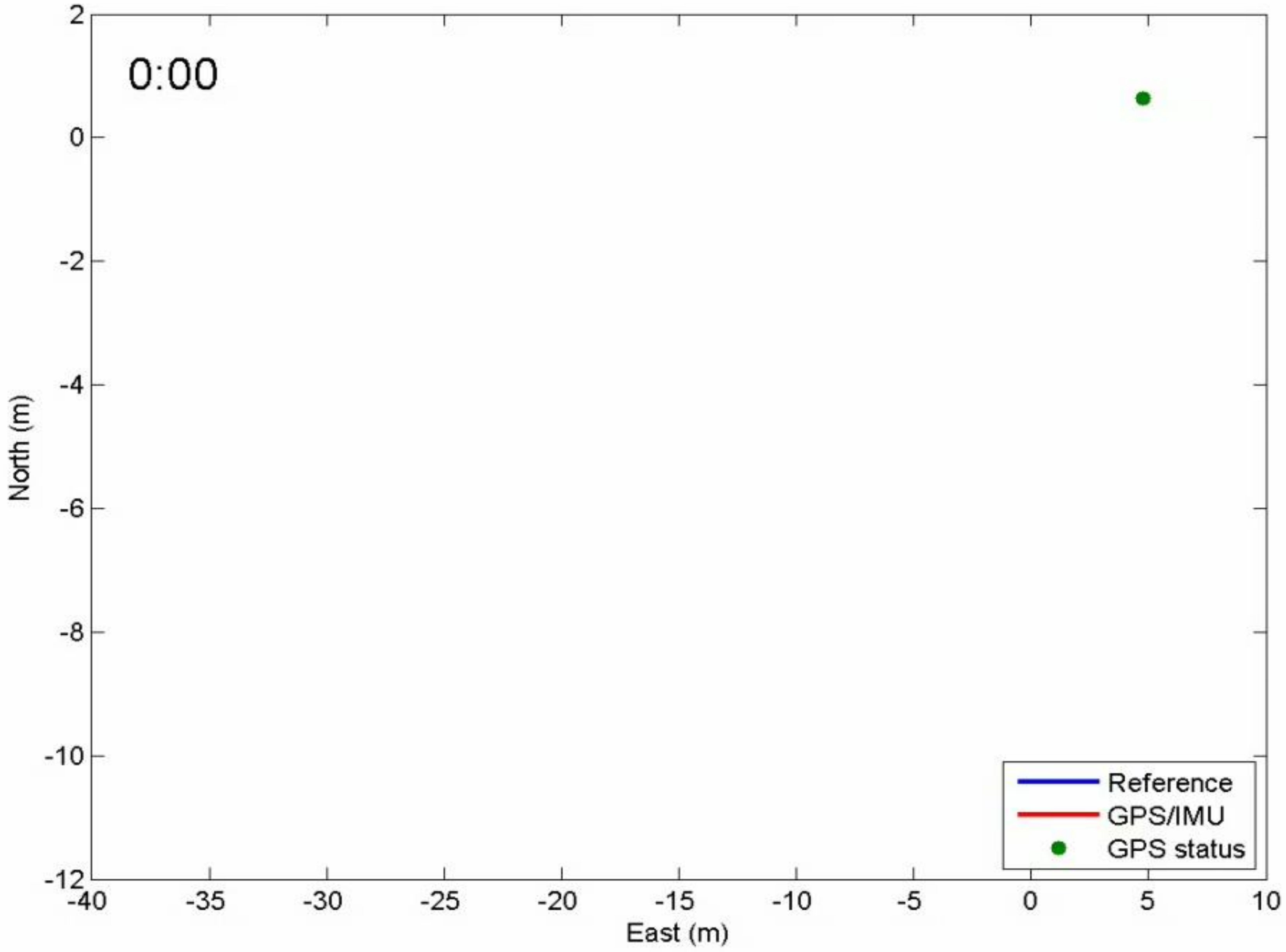
- 3 gyros and 3 accelerometers
- Orientation from integrating gyro output
- Displacement from:
  - Rotate measurements (using gyros)
  - Removing gravity and …
  - Double integrating accelerations

- MEMS-based are getting better
  - Cheaper (higher volumes - Wii, smartphones)
  - Better manufacturing
  - Better calibration

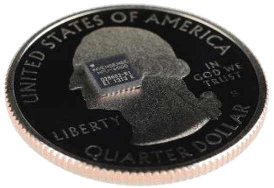
- Key issue is bounding of error growth



GNSS / IMU Integration



Typical UAV IMU Sensors

IMU	Honeywell H-764G	Epson M-G362PDC1	MicroStrain 3DM-GX3-35	Autopilot sensors	Analog Devices ADIS16364
Gyro bias	0.0035°/h	3 °/ h	18 °/ h	> 15 °/ h	25 °/ h
Gyro random walk	0.0035°/$h^{1/2}$	N/A	0.1 °/ $h^{1/2}$	N/A	2 °/ $h^{1/2}$
Accelerometer bias	25 µg	40 mg	< 100 mg	> 60 mg	8 mg
Accelerometer noise	8.3 µg (100Hz bw)	40 mg / $Hz^{1/2}$	100 mg / $Hz^{1/2}$	> 250 mg / $Hz^{1/2}$	270 mg / $Hz^{1/2}$
Power requirements	40 W	30 mA via USB	200 mA via USB	> 4 mA (IMU only)	49 mA

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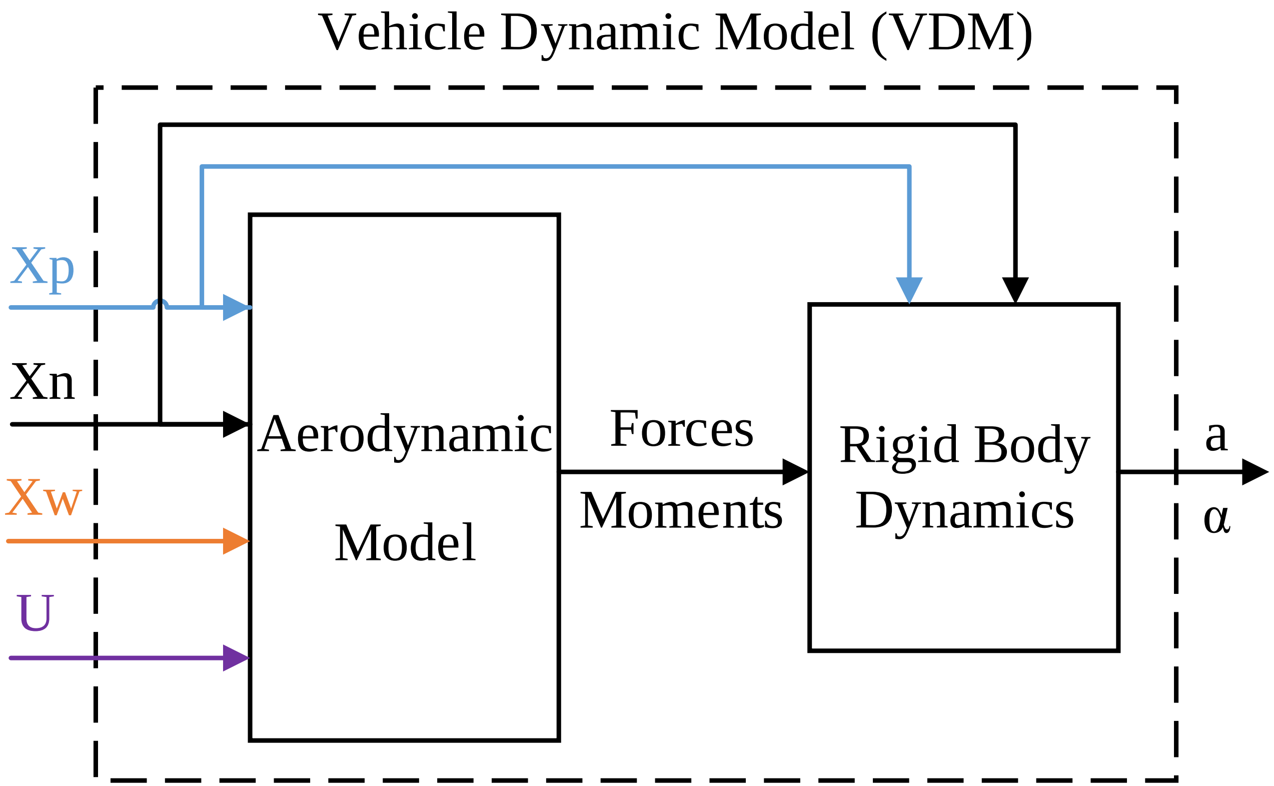
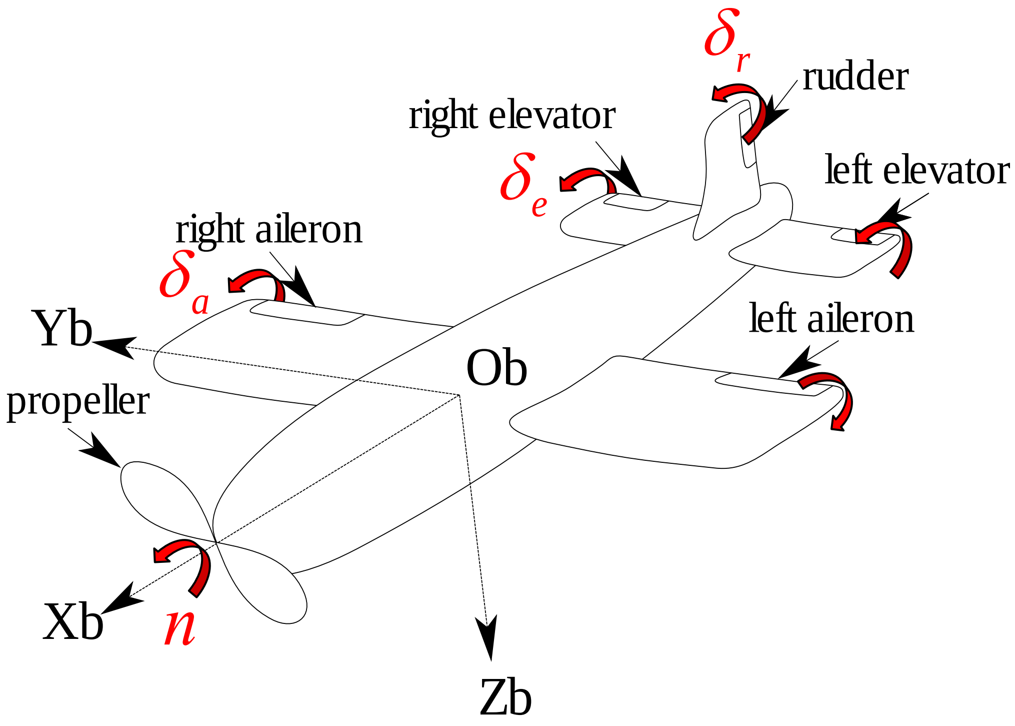
Vehicle Dynamic Modelling





Xp: UAV Parameters
Xn: Navigation States
Xw: Wind Velocity
U: Control Input

a: Linear Acceleration
α: Rotational Acceleration

n: Propeller speed
δ_a: Aileron deflection
δ_e: Elevator deflection
δ_r: Rudder deflection

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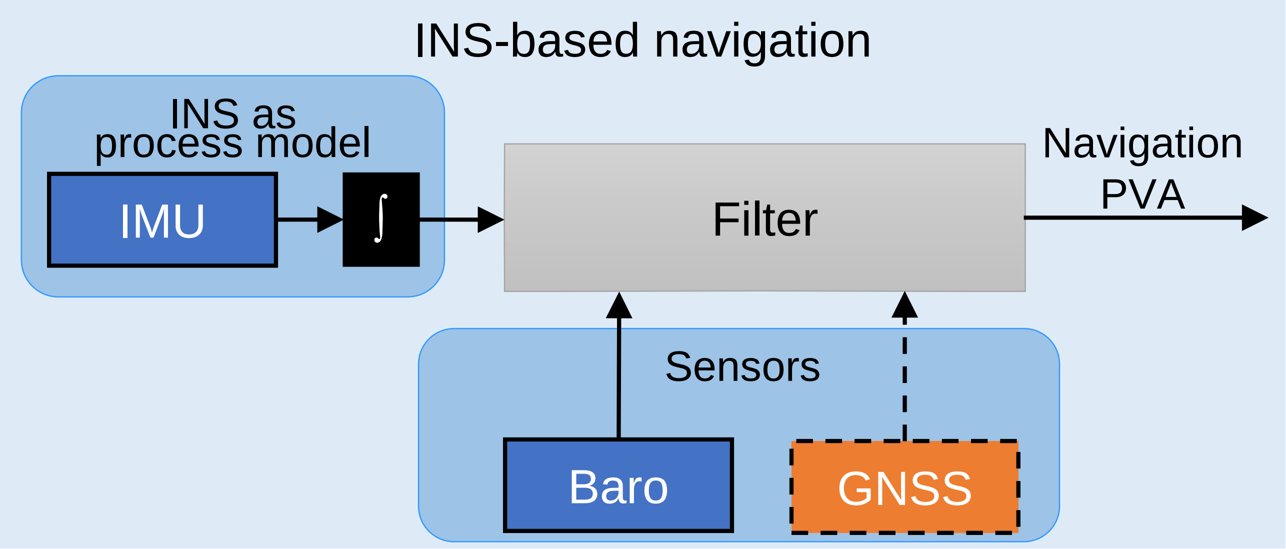
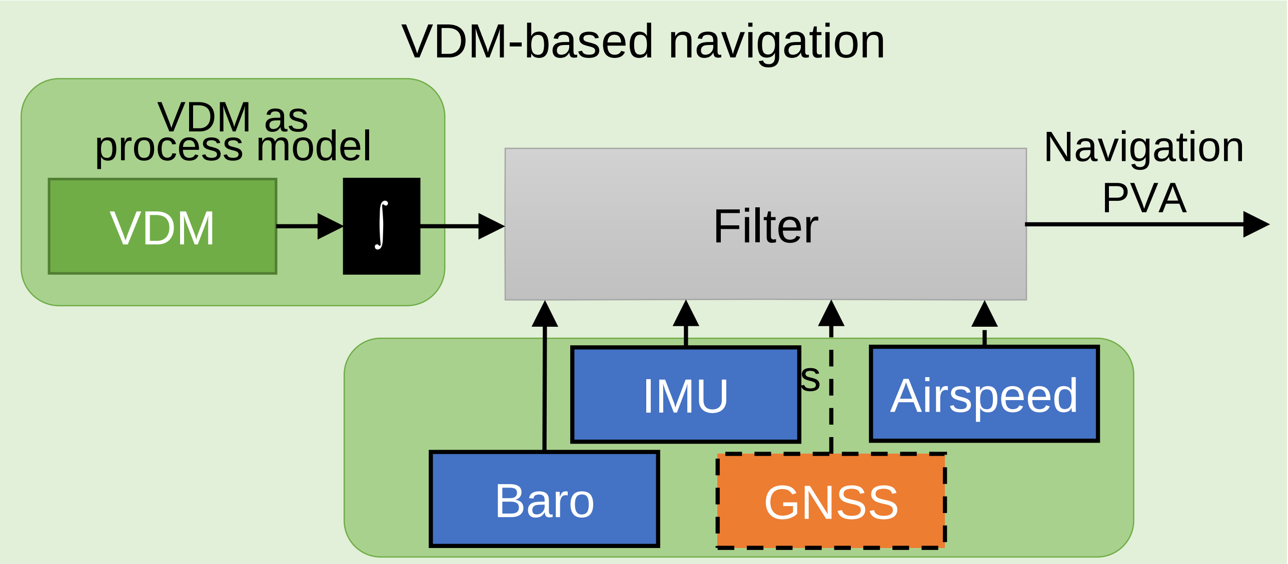
Autonomous Navigation based on VDM





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Simultaneous Localisation and Mapping - SLAM

Mapping can be described by the first question, “what does the world look like?”

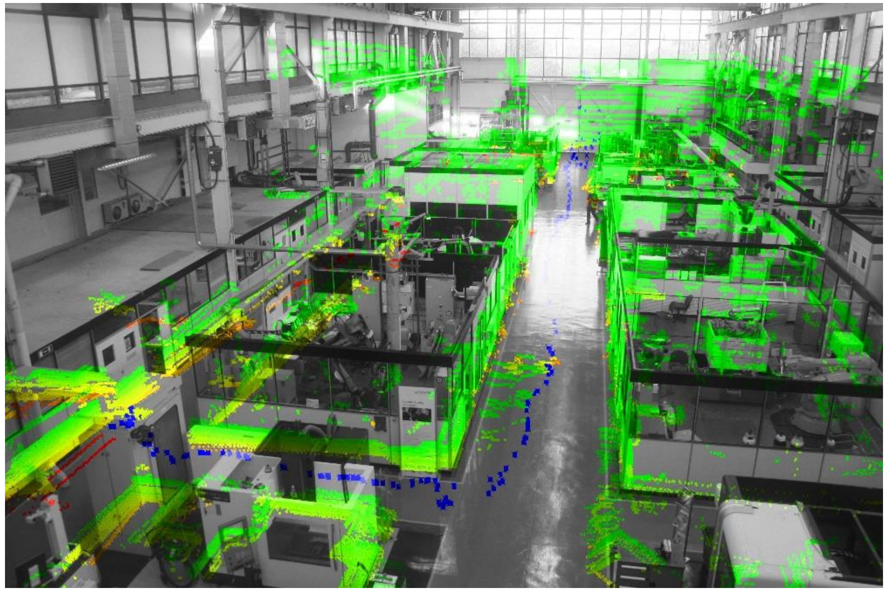
Localization is to answer the second question, “where am I?”

SLAM is defined as the process of building a model leading to a new map, or repetitively improving an existing map, whilst at the same time localising the moving platform within that map

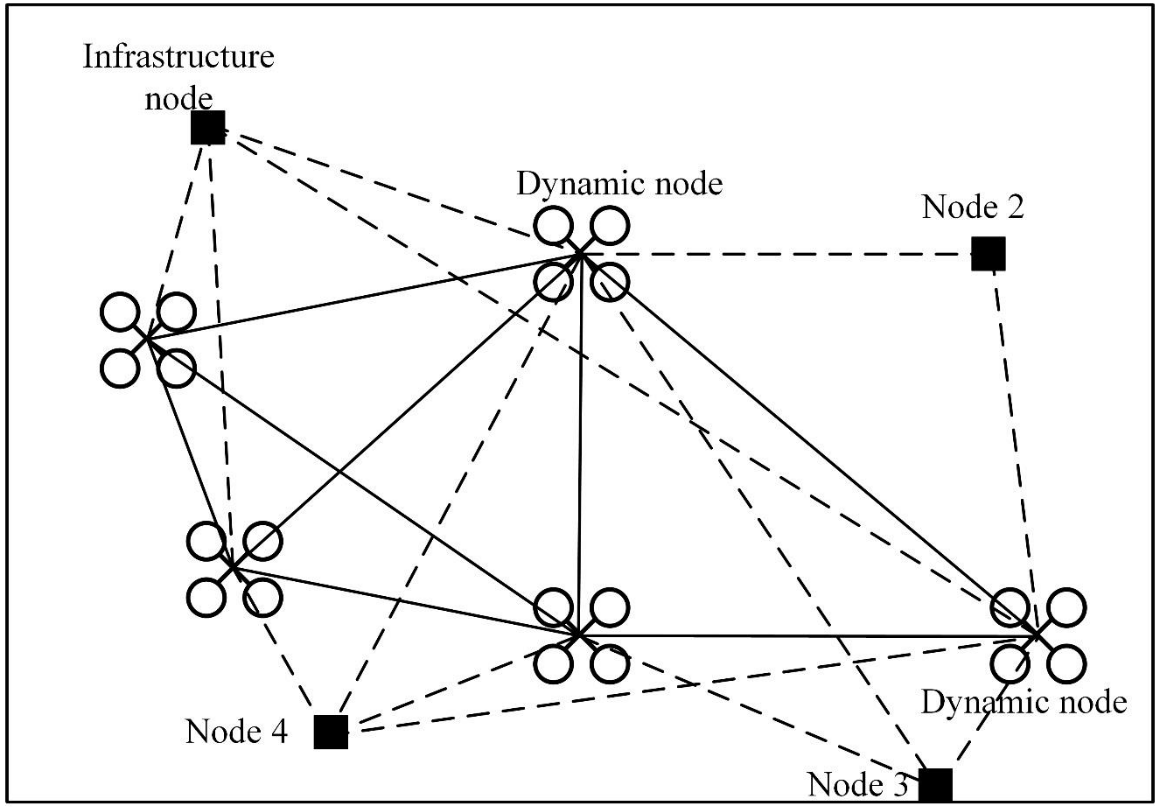
Lidar and / or visual sensing

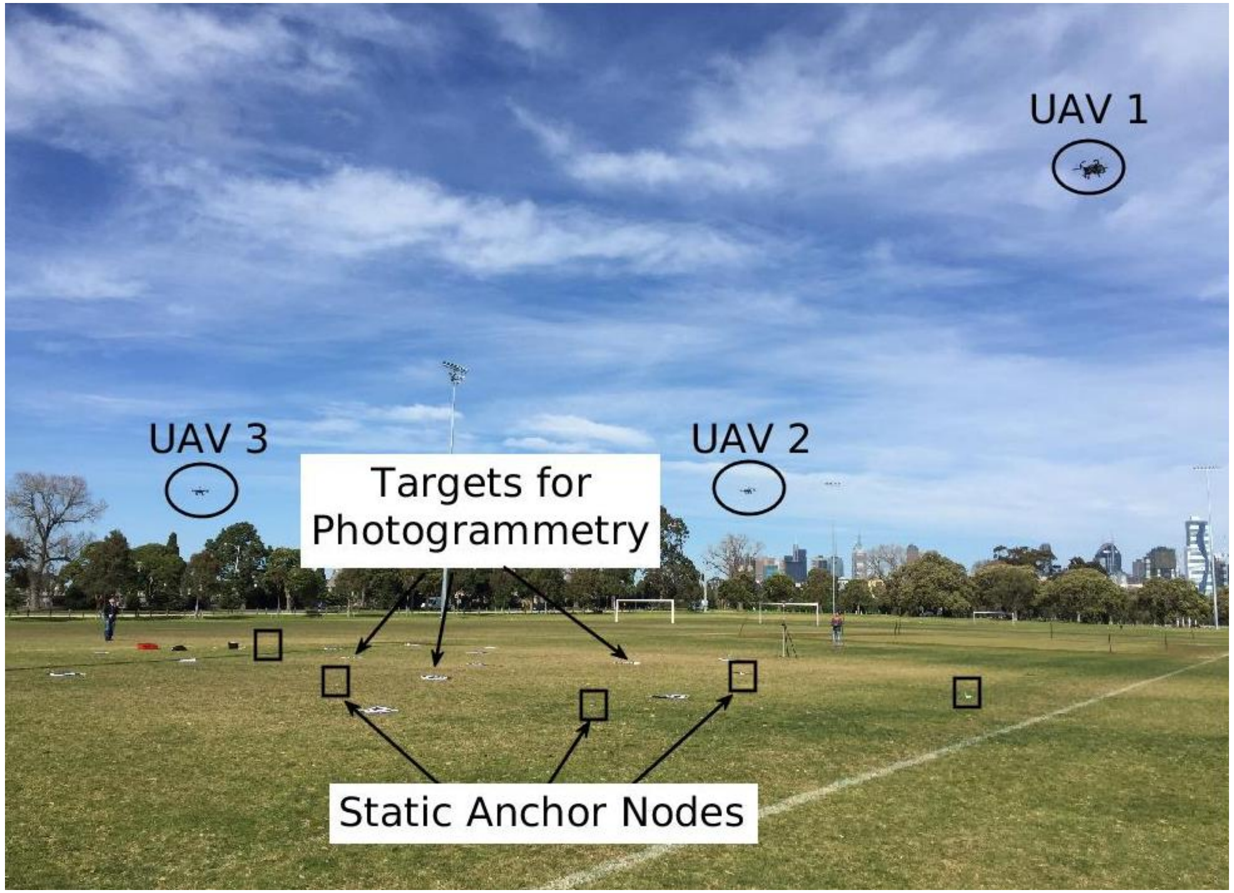
Autonomous UAV operation

Outdoor and indoor applications



Cooperative UAV Localisation





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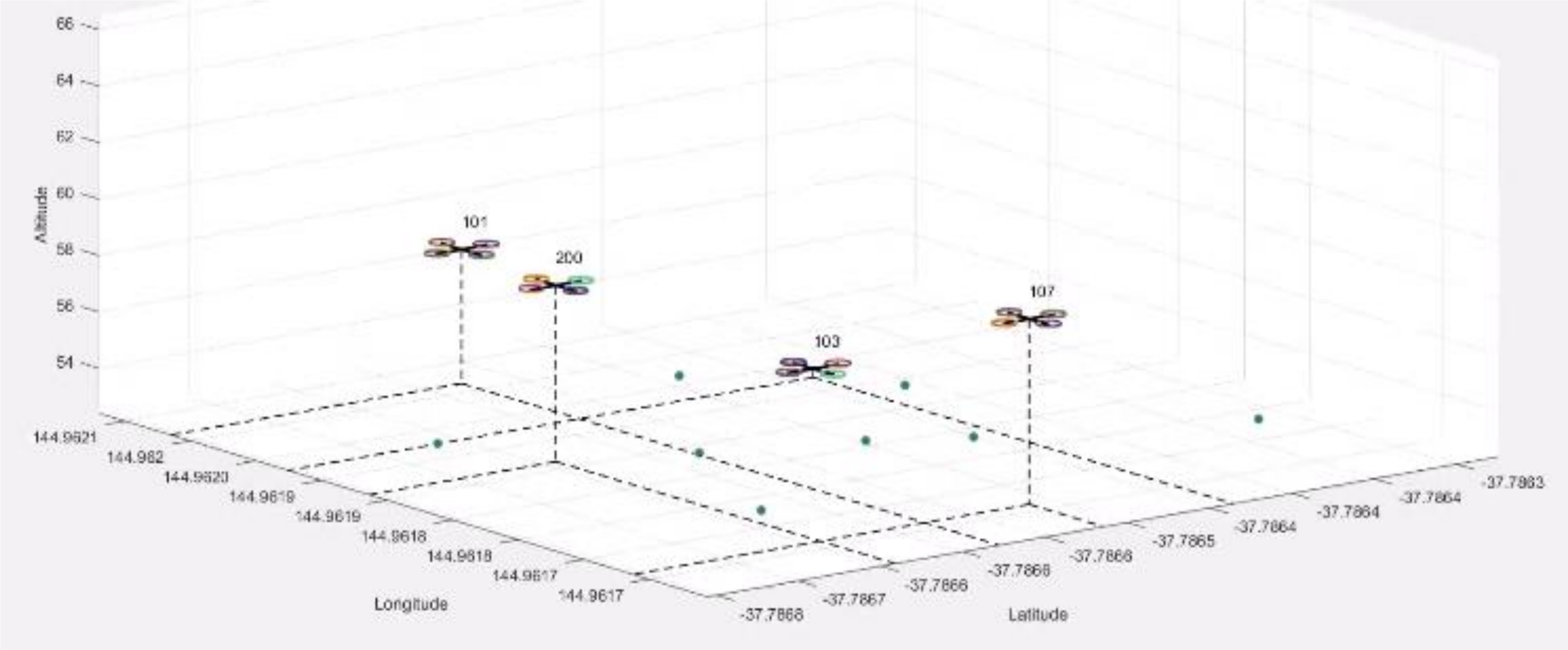
Visualisation of Cooperative UAV Localisation



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Example UAV Operation

Light UAV (<20kg)

Operating below 450 ft.

Survey or inspection of assets

Repeatable flight path.

Safe envelope for navigation should be defined by:

- Proximity to known hazards, plus uncertainty in the location
- Ability to stay on trajectory
- Positioning accuracy and integrity
- c.f. ‘RNP’ (Required Navigation Performance) in aviation

Multi-Phase Operational Approach

En-route Phase

GNSS + SBAS

Integration with high grade IMU for short GNSS outages

Start PPP Computations when UAV is within 20 minutes from asset

or

Run PPP solution in tandem if comms available.

Survey Phase

RTK / PPP + SBAS

Survey of tiles (photogrammetry)

Image Recognition (SLAM)

Positioning and Navigation for UAVs

Summary

- Positioning and navigation sensors often combined
- Use of low-power, weight and cost equipment – low performance
- No definitions of RNP

Split flights into distinct phases

- En-route phase
- Operations Phase

Separate positioning sensors between tasks

- UAV navigation and control
- Sensor positioning

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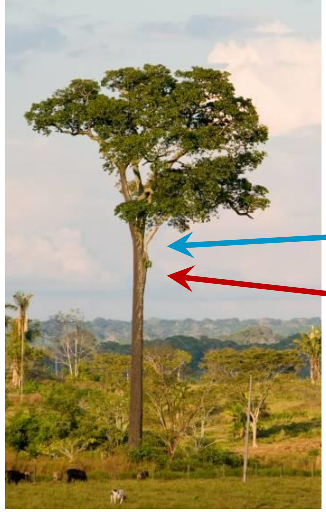
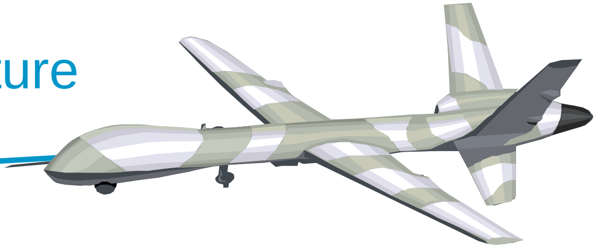
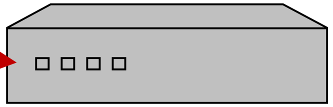
Feature Matching – Absolute Positioning

Identify feature



Determine position of feature relative to vehicle





Match feature with database

Obtain feature position from database

UAV Position = Feature Position – Relative Position

Courtesy of Paul D Groves

Feature Matching – Relative Positioning

Determine position of feature relative to vehicle

Differencing successive relative positions gives the vehicle motion

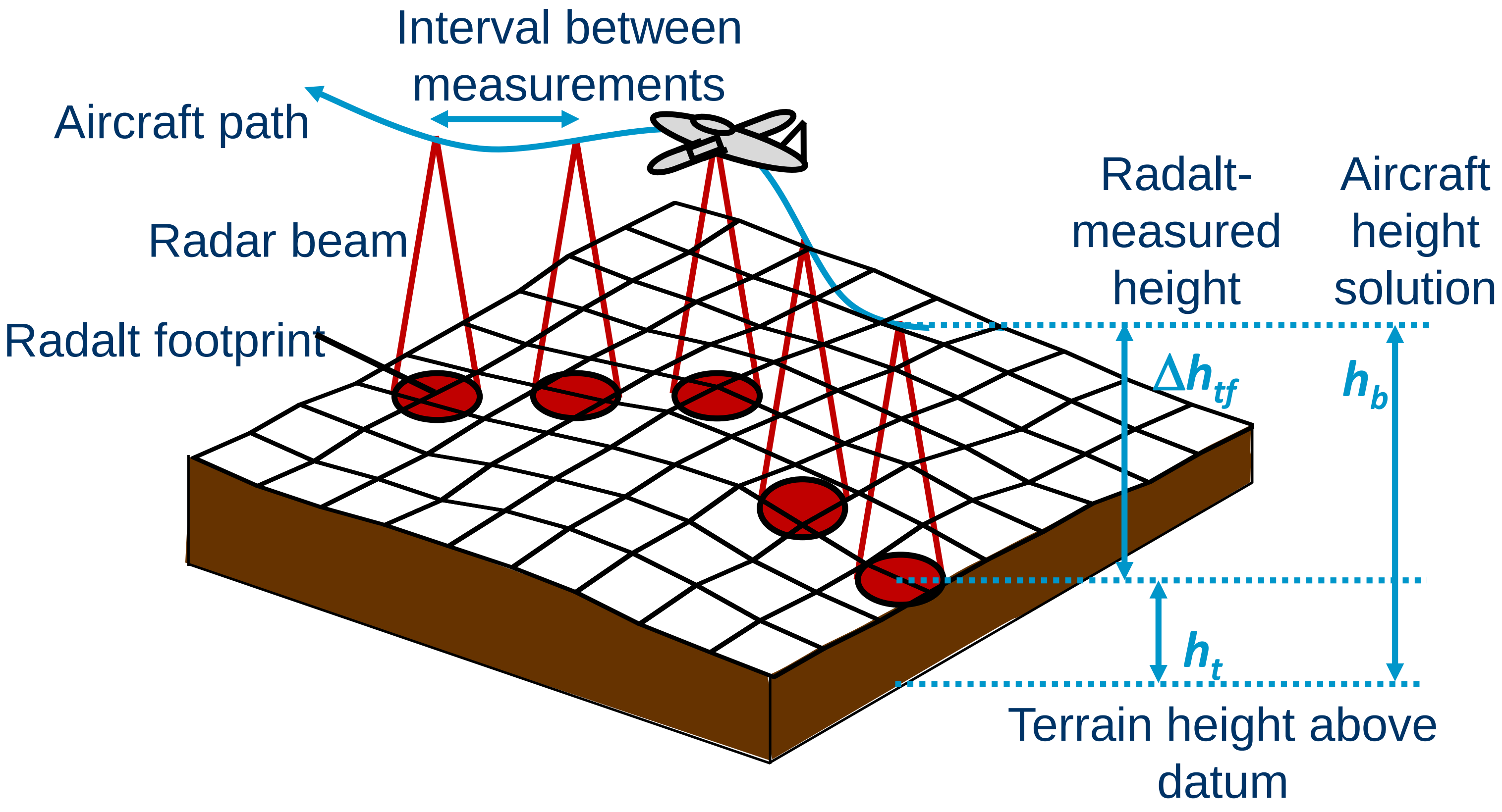
Identify feature and match to previous time

No database

Dead-reckoning technique

Courtesy of Paul D Groves

Terrain Referenced Navigation



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