University of Nottingham
Nottingham Geospatial Institute

Navigating without a Navigator

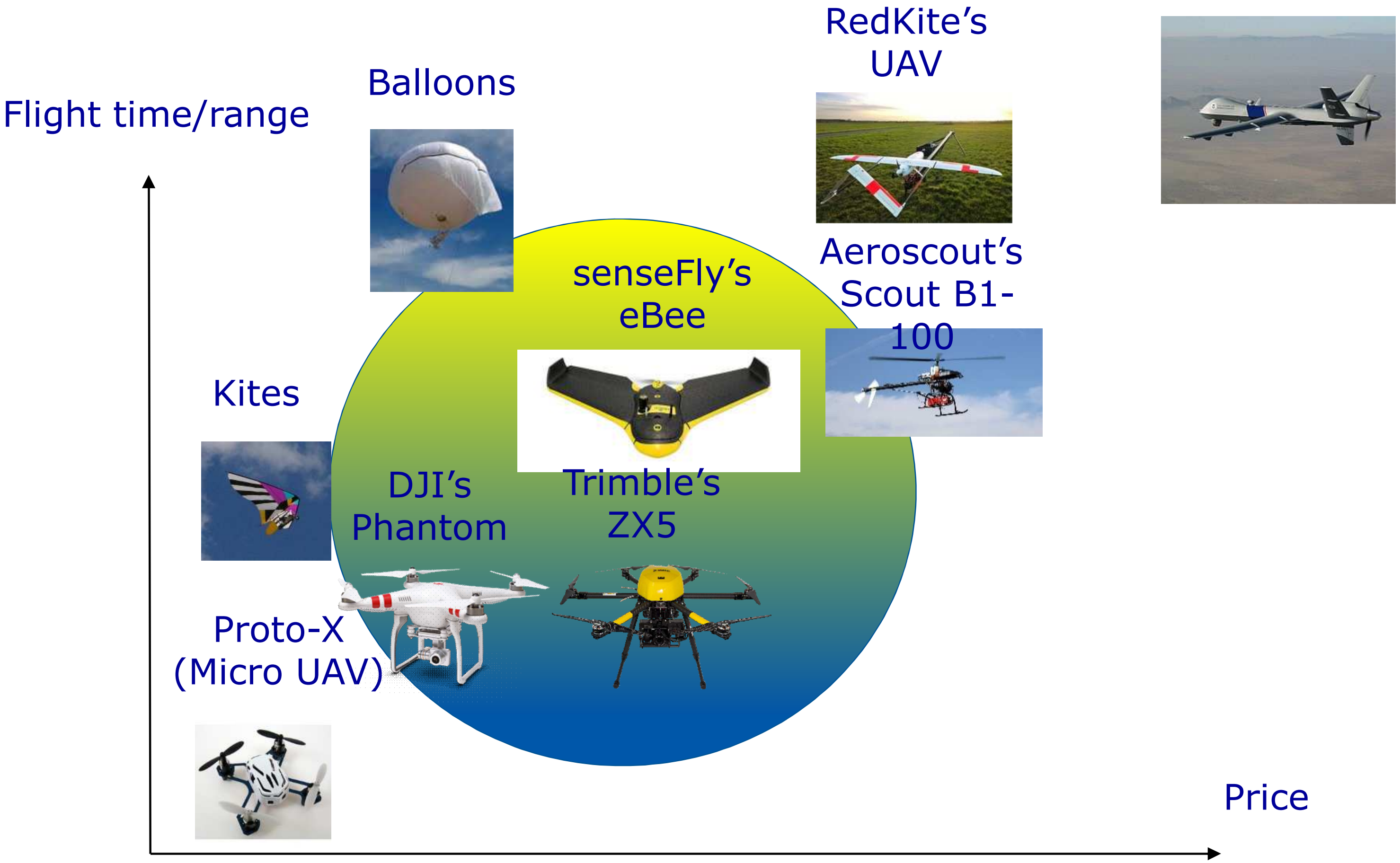
A Review of Positioning and Navigation Technologies for UAVs

Professor Terry Moore

Professor of Satellite Navigation
Nottingham Geospatial Institute
University of Nottingham

University of Nottingham
Nottingham Geospatial Institute

UAV Platforms



Courtesy of The Ohio State University

Comparison of UAV Platforms

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

Courtesy of
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), autonomous, BVLOS Operations
- Different levels of accuracy and integrity are required (RNP)
- But, often combined into a single integrated payload

University of Nottingham
Nottingham Geospatial Institute

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

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

Partial credit

The Ohio State University

University of Nottingham
Nottingham Geospatial Institute

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 pulse accuracy	30 ns
Power requirements	121 mW
Weight without / with equipment	2 gram 17 gram

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
Weight without / with equipment	24 gram 300 gram

Courtesy of
The Ohio State University

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

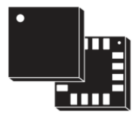
Orientation from integrating gyro output

Displacement from:

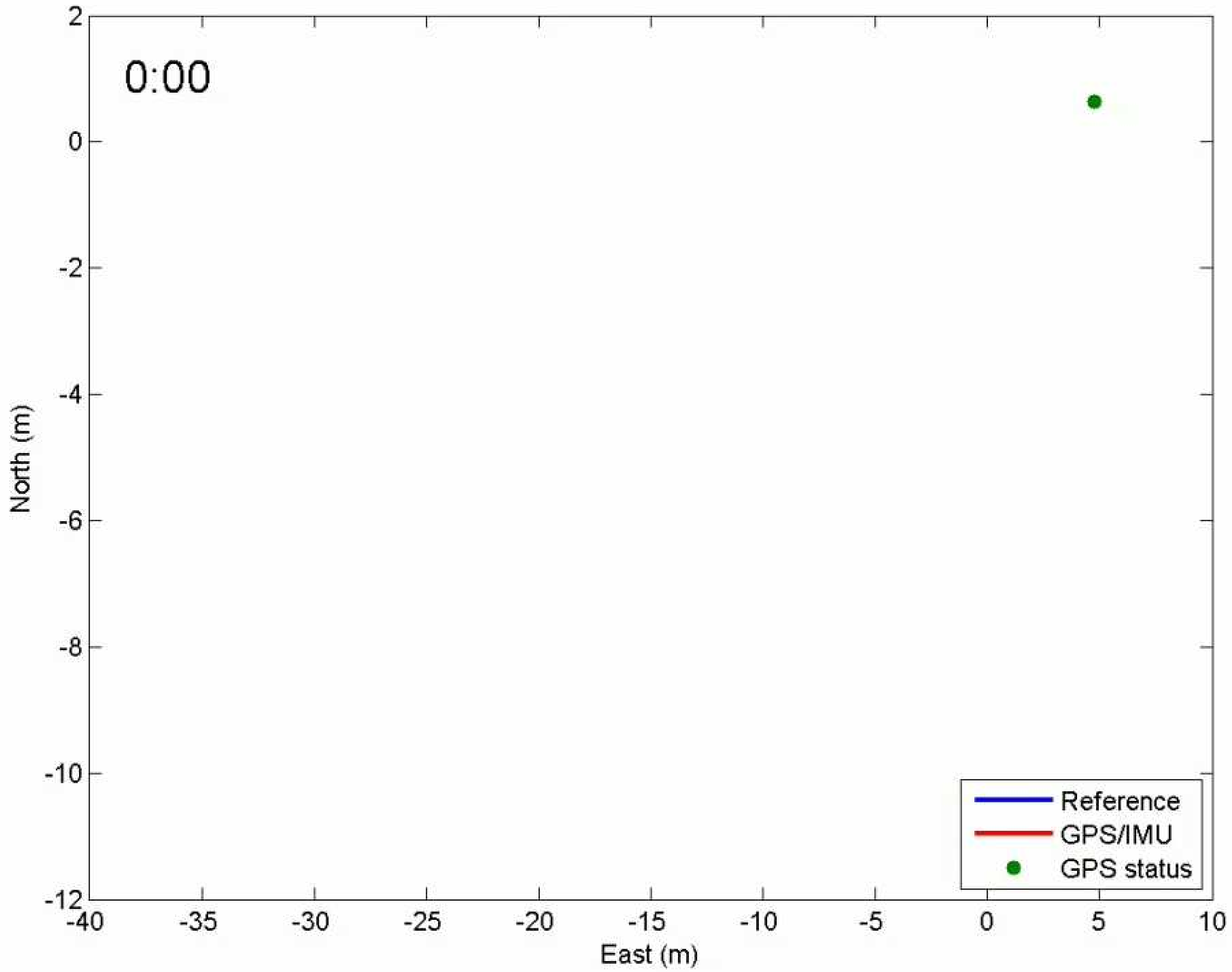
- Rotate measurements (using gyros)
- Removing gravity and …
- Double integrating accelerations

MEMS-based are getting better

- Cheaper (higher volumes - Wii, smartphones)
- Better manufacturing
- Better calibration

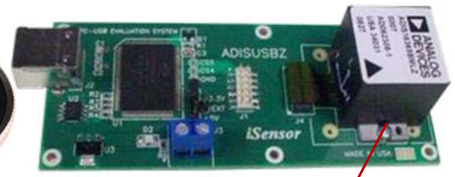


GNSS / IMU Integration



University of Nottingham
Nottingham Geospatial Institute

Typical UAV IMU Sensors

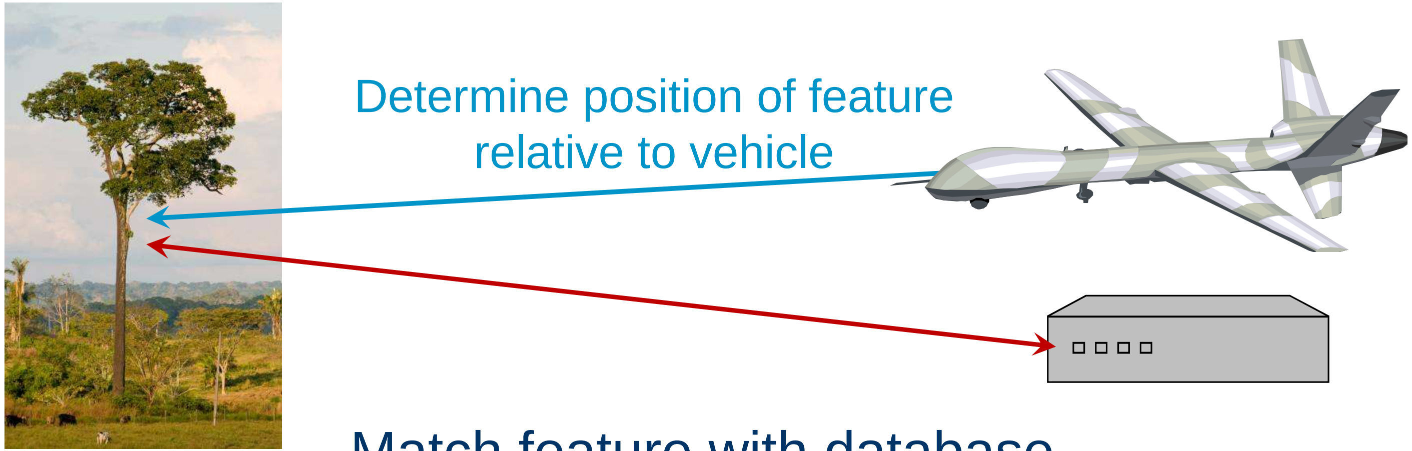


Honeywell H-764G	IMU	Epson M-G362PDC1	MicroStrain 3DM-GX3-35	Autopilot sensors	Analog Devices ADIS16364
0.0035°/h	Gyro bias	3 °/ h	18 °/ h	> 15 °/ h	25 °/ h
0.0035°/h$^{1/2}$	Gyro random walk	N/A	0.1 °/ h$^{1/2}$	N/A	2 °/ h$^{1/2}$
25 µg	Accelerometer bias	40 mg	< 100 mg	> 60 mg	8 mg
8.3 µg (100Hz bw)	Accelerometer noise	40 mg / Hz$^{1/2}$	100 mg / Hz$^{1/2}$	> 250 mg / Hz$^{1/2}$	270 mg / Hz$^{1/2}$
40 W	Power requirements	30 mA via USB	200 mA via USB	> 4 mA (IMU only)	49 mA
8.4 kg >10 kg	Weight without / with equipment	7 gram 30 gram	23 gram 200 gram	> 50 gram	16 gram

Courtesy of
The Ohio State University

Feature Matching – Absolute Positioning

Identify feature



Match feature with database

Obtain feature position from database

UAV Position = Feature Position – Relative Position

Courtesy of Paul D Groves

University of Nottingham
Nottingham Geospatial Institute

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

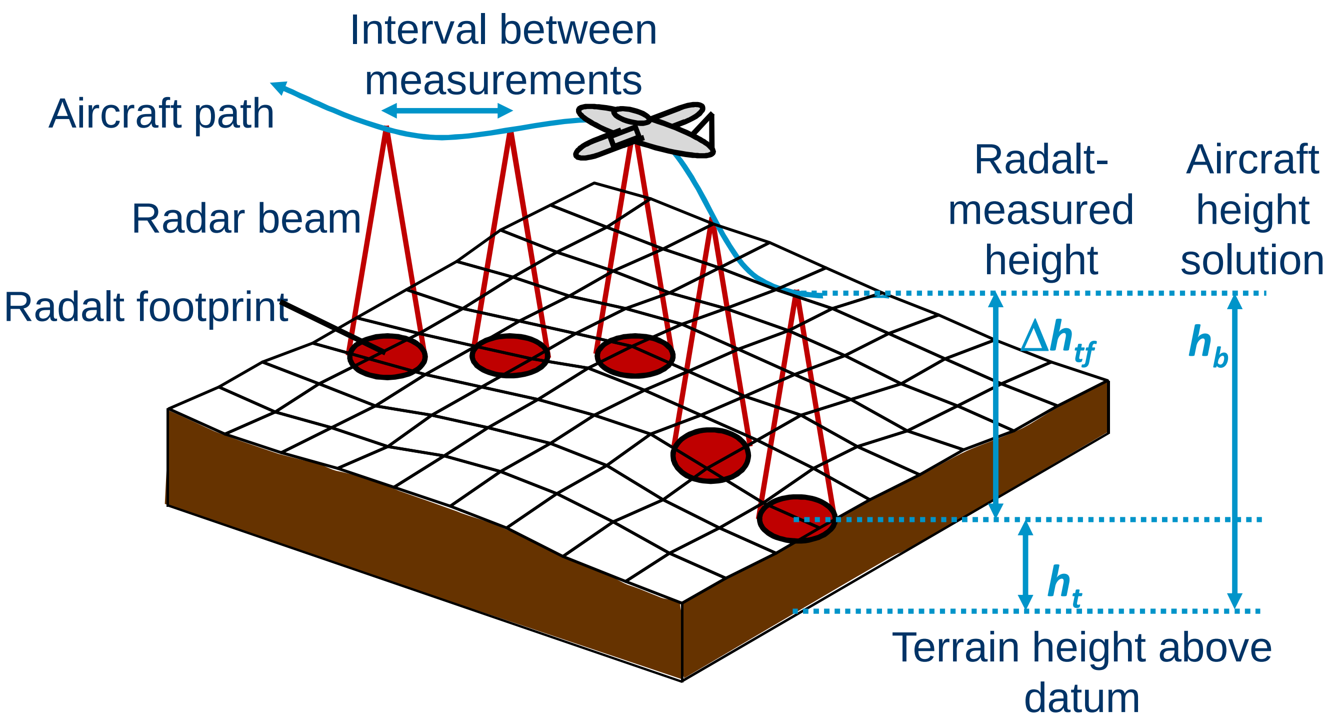
No database

Dead-reckoning technique

Courtesy of Paul D Groves

UCL

Terrain Referenced Navigation



From Paul D Groves, Principles of GNSS, Inertial and Multisensor Integrated Navigation Systems, Artech House, 2008/2013. Reproduced with permission.”

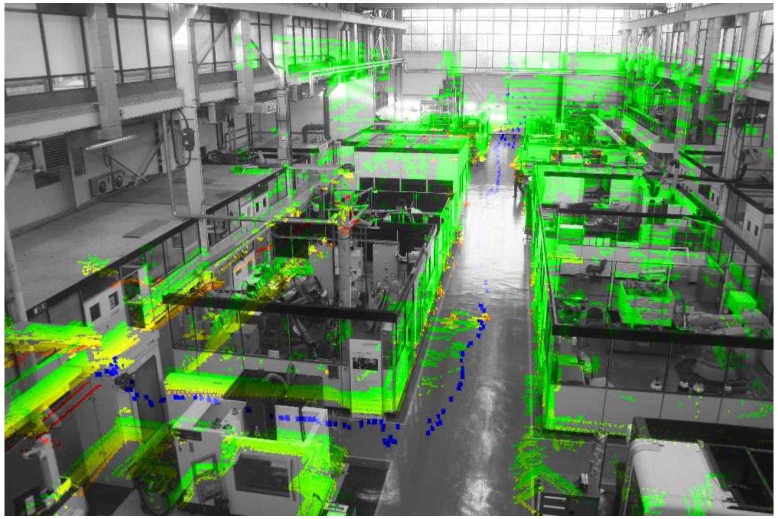
University of Nottingham
Nottingham Geospatial Institute

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

Typical Operational Conditions

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)

University of Nottingham
Nottingham Geospatial Institute

Contact Details

Professor Terry Moore
Director of the NGI
Nottingham Geospatial Building
The University of Nottingham
Triumph Road
Nottingham
NG7 2TU

Telephone: +44 (0) 115 951 3886
Fax: +44 (0) 115 951 3881
Email: terry.moore@nottingham.ac.uk
WWW: www.nottingham.ac.uk/ngi