Indoor Positioning: Where are we?

12th November 2025

This event is delivered by the Cambridge Wireless Location SIG

CAMBRIDGE WIRELESS

In partnership with The Royal Institute of Navigation

ROYAL INSTITUTE OF NAVIGATION

Kindly hosted by Queens' College, Cambridge

QUEENS' COLLEGE CAMBRIDGE

CAMBRIDGE WIRELESS

WELCOME AND INTRODUCTION

Michaela Eschbach

CEO

Cambridge Wireless

WHO WE ARE

Cambridge Wireless (CW) is a global not-for-profit membership organisation at the forefront of innovation in connectivity and digital technology.

Since 2000, CW has united industry leaders across connected devices, networks, software, data analytics, telecoms, satellites, and more.

We help our members...

COLLABORATE
LEARN
SHAPE THE FUTURE

CAMBRIDGE WIRELESS

WHAT WE DO

We bring together leaders, innovators, and experts through a range of initiatives designed to foster collaboration, drive innovation, and support professional growth.

From flagship conferences and networking events to strategic innovation projects and skills development, our programmes create valuable opportunities for members.

- Special Interest Groups (SIGs)
- Events and Conferences
- Academy and Training Courses
- Executive Meetings
- Knowledge Bank
- Partnership Programmes
- Connections, Visibility and Exposure

CAMBRIDGE WIRELESS

SPECIAL INTEREST GROUPS (SIGs)

SIGs are at the heart of CW's mission to help our members to Collaborate, Learn and Shape the Future. Built by and for our membership, with content shaped and delivered by the SIG.

- Focus on specific technology and market sectors
- Keep members up to date with industry developments
- Create opportunities for influencing developments
- Explore new business opportunities
- Encourage networking

CAMBRIDGE WIRELESS

- Academic & Industry
- Artificial Intelligence
- Connected & Intelligent Places
- Connected Thinking
- Content Production & Delivery
- Future Devices & Technologies
- Health Tech
- Location
- Mobile Networks
- Non-Terrestrial Networks
- Radio Technology
- Security, Privacy, Identity & Trust
- Sustainability
- Wireless Heritage

EVENTS & CONFERENCES

Free or discounted programmes for our members.

CONFERENCES:
CW International Conference (CWIC)
CW Technology & Engineering Conference (CWTEC)
Cambridge Tech Week (CTW)

MEMBER-LED EVENTS:
Seminars, masterclasses, subject/knowledge specific

CAMBRIDGE WIRELESS

MEMBER DINNERS

Expand connections with industry leaders, innovators, and the wider tech ecosystem.

Engage in thought-provoking discussions in a historic Cambridge setting.

- Free for Founder Members
- 5 tickets per event
- 3 dinners per calendar year
- Networking drinks reception
- Dinner in a university college hall
- Post-dinner keynote address

CAMBRIDGE WIRELESS

The Location SIG

The purpose of the Location SIG is to promote and further the adoption of location as a value-added facility for a range of applications.

David Bartlett

Bob Cockshot

Ramsey Faragher
The Royal Institute of Navigation

Ben Tarlow
Qualcomm Technologies International

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Welcome & Introduction from our Event Partner The Royal Institute of Navigation

Ramsey Faragher

CEO,

The Royal Institute of Navigation

https://rin.org.uk

Agenda

10:45 **Andy Ward, Ubisense** - 'Wish you were here?'
Q&A

11:10 **Paul Bearpark, 42T-** 'UWB indoor and outdoor positioning: European regulations update'
Q&A

11:35 Bullet presentations from:

- **Fredi Nonyelu, Briteyellow - www.briteyellow.com**
- **Jon Stone, Waymap - www.waymapnav.com**

11:45 **Mayank Batra, Qualcomm Technologies International, Ltd.** - Using Bluetooth Channel Sounding to improve indoor positioning'
Q&A

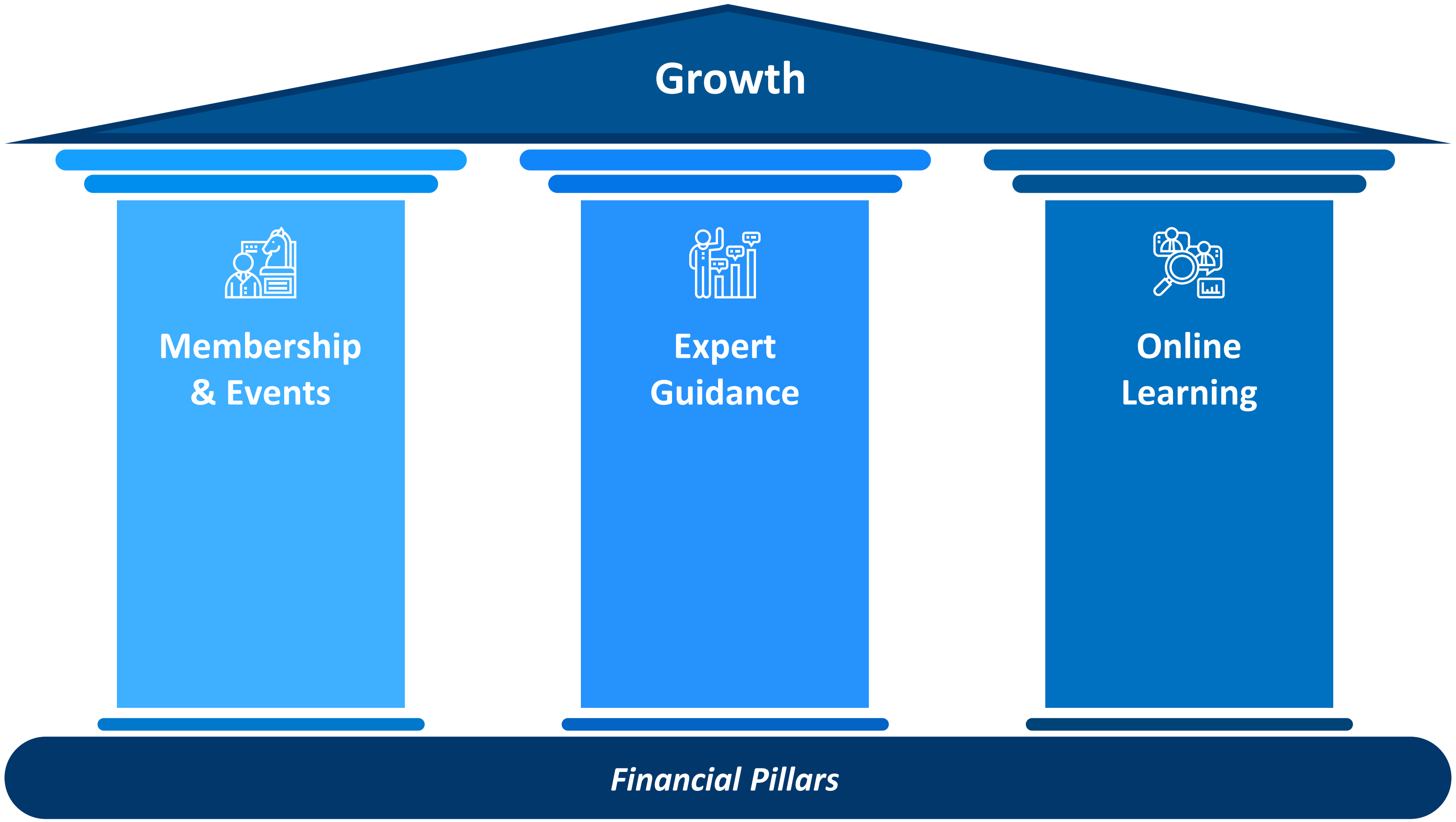
12:10 **Chris Cobb National Physical Laboratory -** 'Time, the Invisible Utility'

12:30 Lunch & networking in the Old Hall

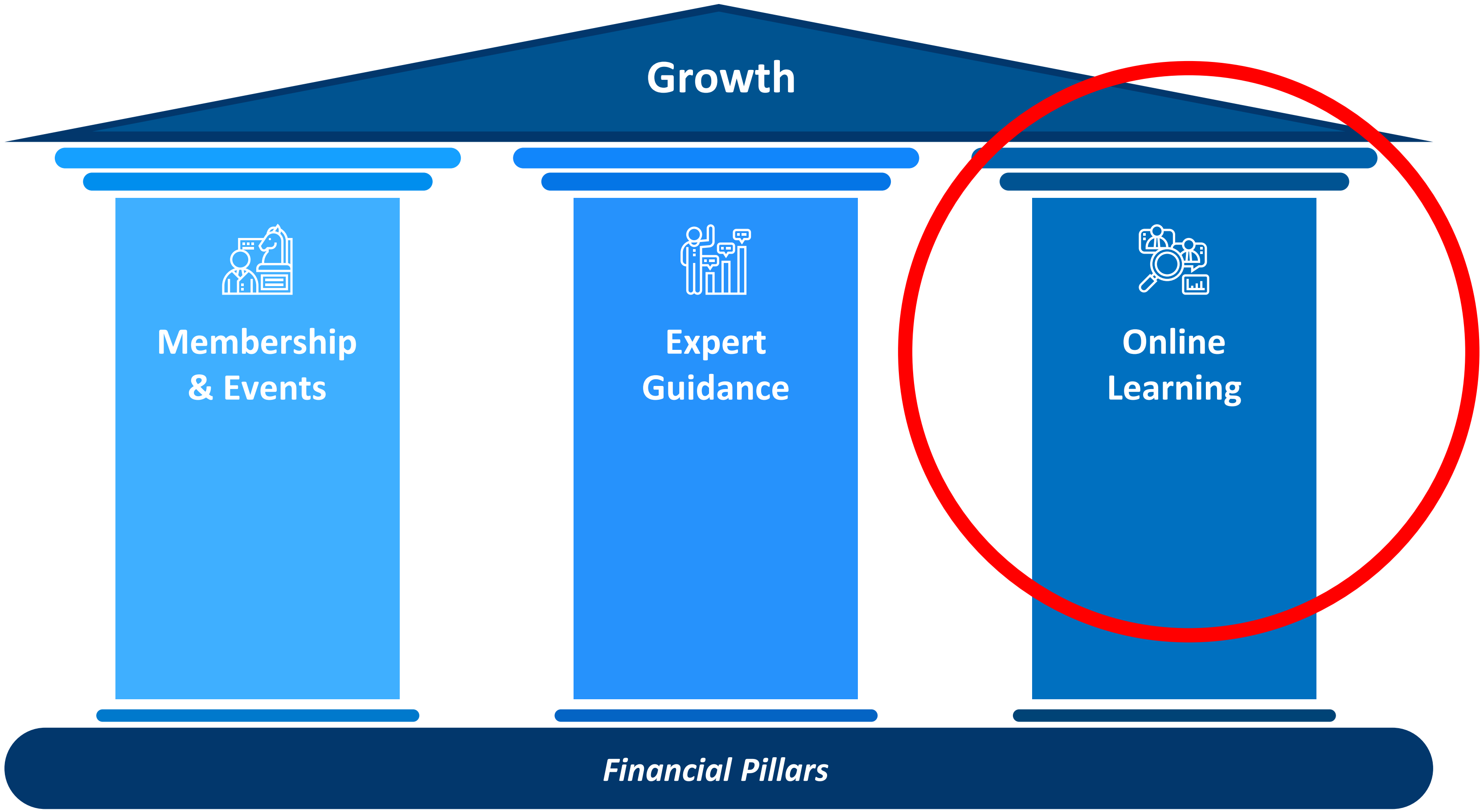
Where are we?

Welcome: RIN Director Dr Ramsey Faragher

RIN strategy 2025-2030



RIN strategy 2025-2030



Welcome to the RIN Learning Centre

Explore expert-led courses, gain new skills, and stay ahead in the world of positioning, navigation, and timing.

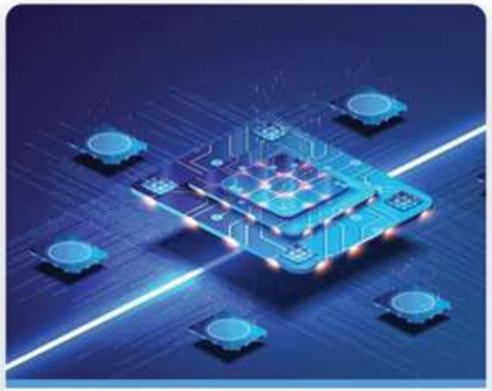
RIN Homepage

Welcome to the RIN Learning Centre

PNT (POSITIONING, NAVIGATION AND TIMING)

Content coming soon.

MORE



QUANTUM TECHNOLOGIES

Content coming soon.

MORE

SCIENCE COMMUNICATION

Content coming soon.

MORE

SPACE

Content coming soon.

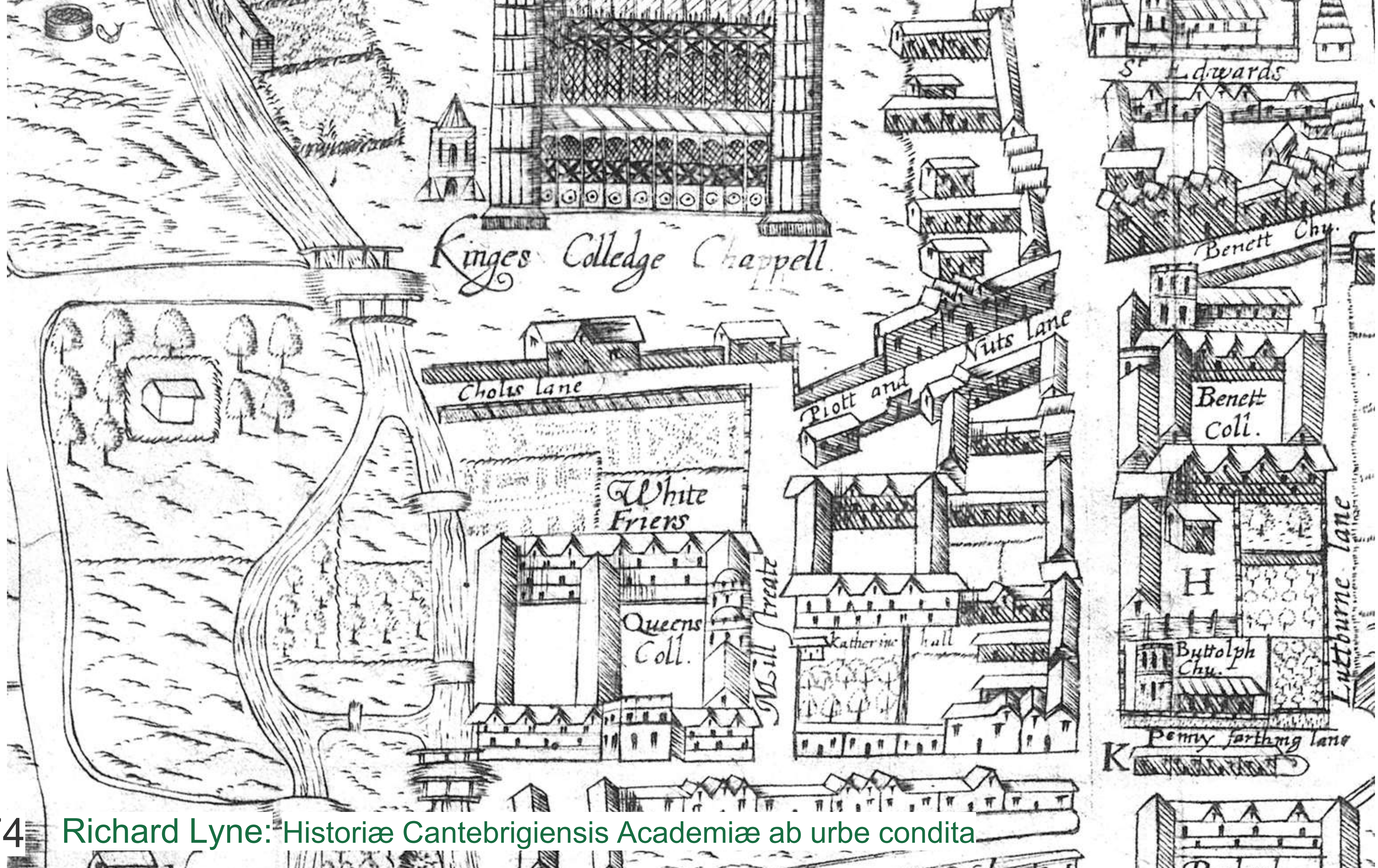
MORE

AVIATION

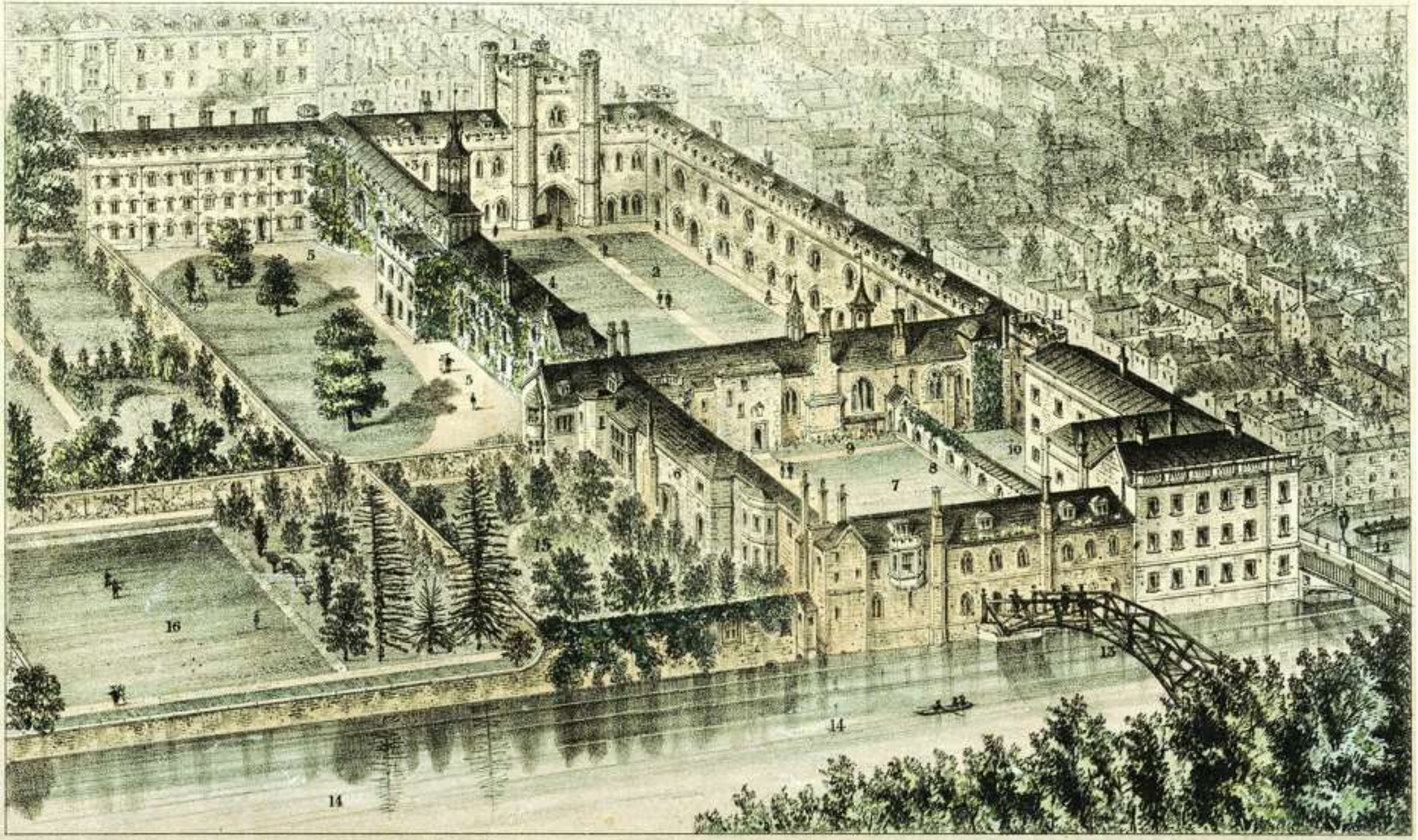
MARITIME

STANDARDS AND

WAYFINDING



1574 Richard Lyne: Historiæ Cantebrigiensis Academiæ ab urbe condita

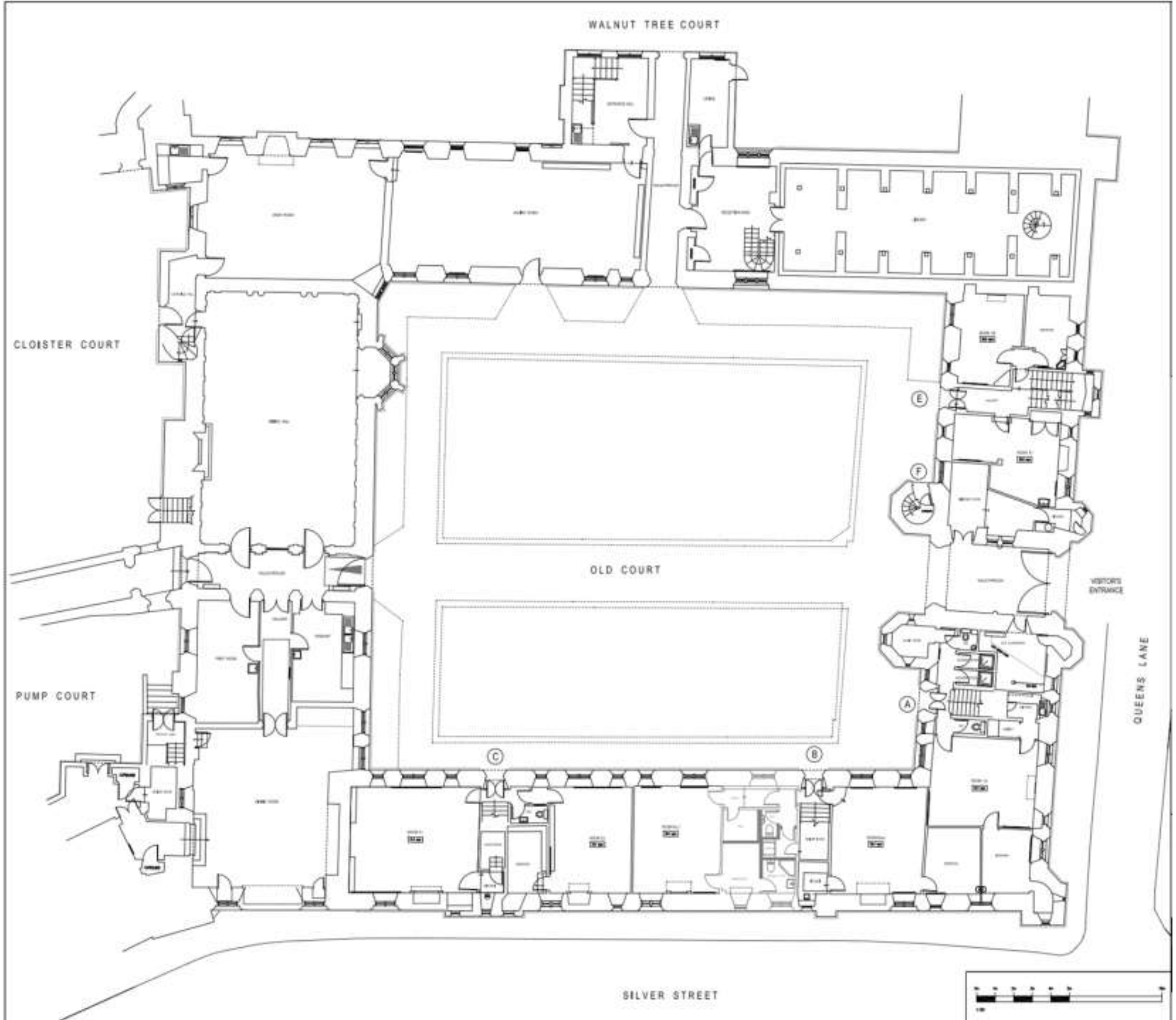


DRAWN ENGRAVED AND PUBLISHED BY H. HYDE 34 RICHARD STREET ISLINGTON LONDON AUGUST 12TH 1856.

A BIRD'S EYE VIEW OF
QUEENS' COLLEGE, CAMBRIDGE.

1. Entrance Tower
2. First Court
3. The Chapel
4. The Library
5. Walnut Tree Court
6. The President's Lodge
7. Second Court
8. Part of the Cloisters
9. The Hall
10. Fellows Buildings, Pump Court.
11. Erasmus' Tower
12. Small Bridge
13. Bridge leading to the Fellows Garden and Grove
14. River Cam.
15. The President's Garden
16. The Fellows Bowling Green

1856


WALNUT TREE COURT
CLOISTER COURT
OLD COURT
PUMP COURT
VISITOR'S ENTRANCE
QUEENS LANE
SILVER STREET
A
B
C
E
F

2020


Search Google Maps
Share
Queens' College
Google Street View
Nov 2015
Google Maps

‘Wish you were here?’

Andy Ward,

CTO,

Ubisense

https://ubisense.com

Ubisense

Transforming Physical Space into SmartSpace®

Wish You Were Here?

Andy Ward

November 2025

Ubisense and location-awareness

- Founded in 2002 to commercialise in-building location-aware solutions:

Ubisense uses location data to discover relationships
between **products**, **processes** and **people**,
giving you unrivalled visibility and control of your operations

- Heritage from Cambridge University Computer Lab and AT&T Labs Cambridge
- HQ'd in Cambridge, with US & German field offices, and partner support in Japan

- Provides full-stack solutions for industrial / commercial / military customers
- Major markets are automotive, aerospace, transit and defence

Ubisense location technology components

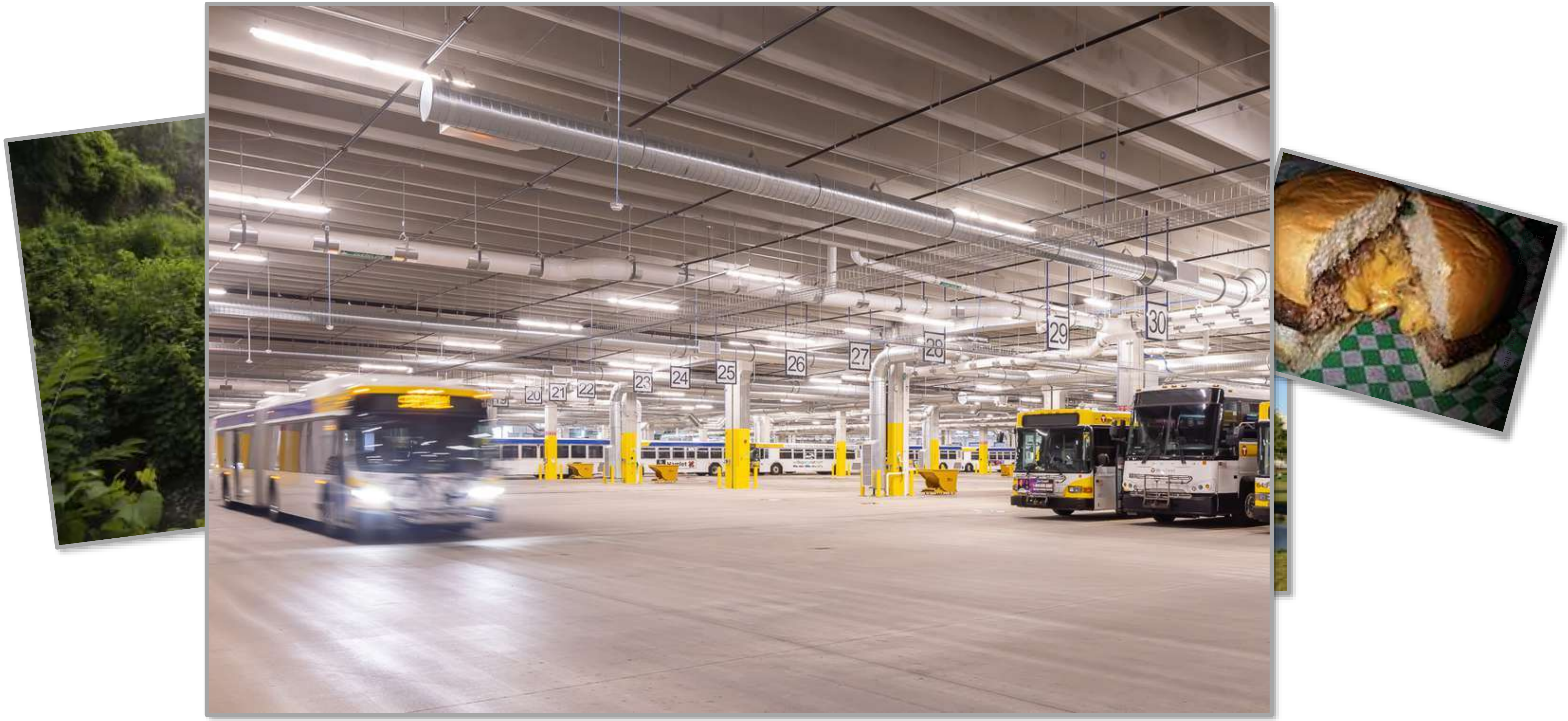
- **Dimension4** ultrawideband (UWB) location system
  - Mobile, battery-powered tags (up to 25y lifetime @ 1Hz)
  - Fixed sensor infrastructure (measuring signal AoA+TDoA)
  - 10-30cm 3D accuracy in indoor environments
  - Very high system capacity (200 updates/s per tag, 100k+ tags)
  - Optional GNSS/RTK-GNSS for indoor+outdoor location

- **SmartSpace** location platform software
  - Takes data from any location or identification sensor
  - Builds sensor-agnostic real-time digital twin of site
  - Supports visibility, monitoring and control solutions
  - Makes building new location-aware applications easy

Kölliken, Switzerland

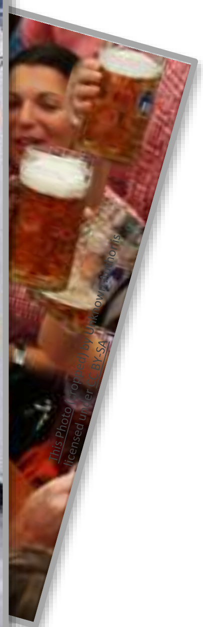
Kölliken, Switzerland
Personnel Safety at Hazardous Waste Site, 2005-2018

Minneapolis, USA



Minneapolis
Bus Depot Management, 2007-

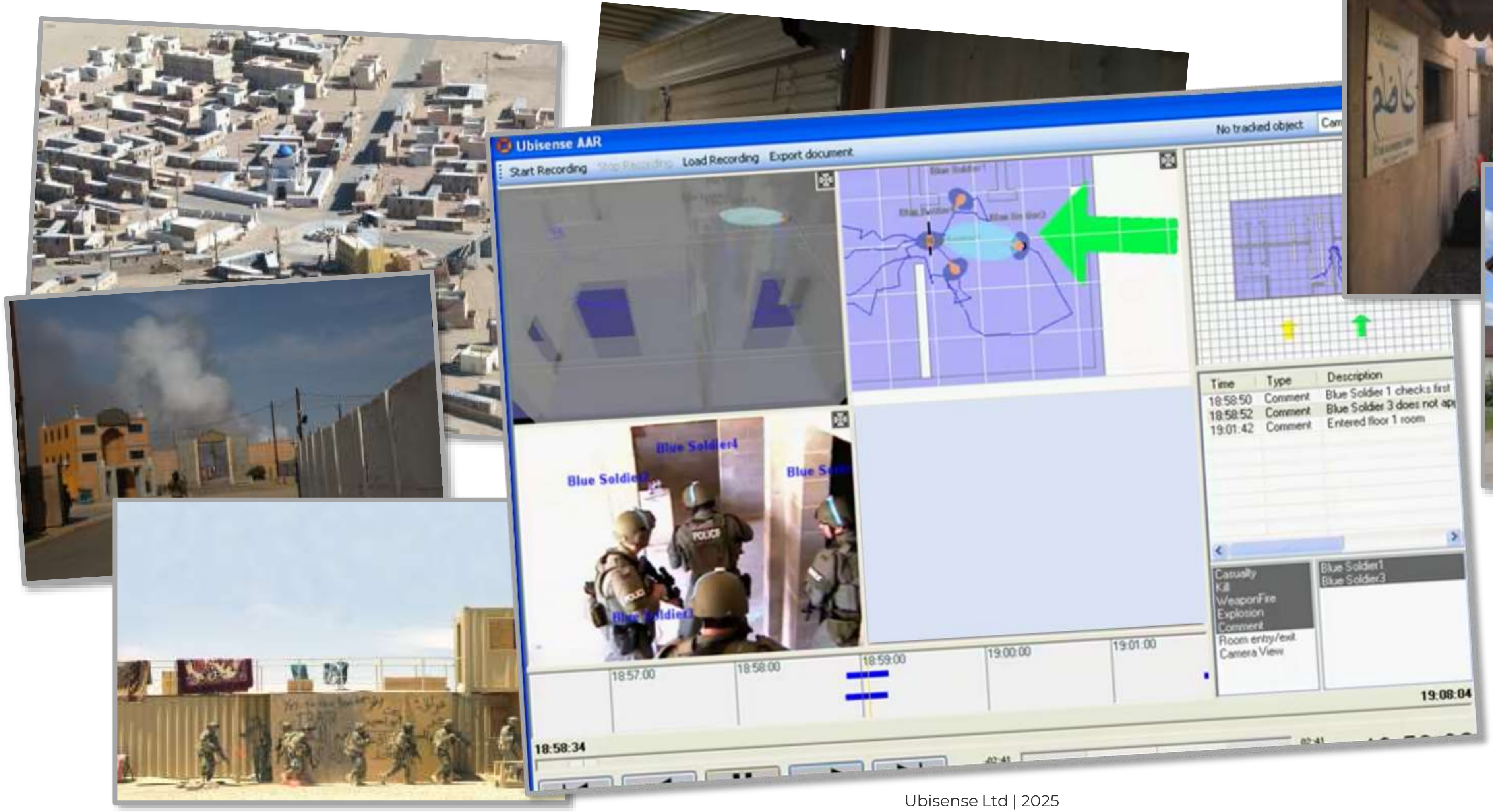
Bavaria



Bavaria
Assembly Tool Control, 2008-

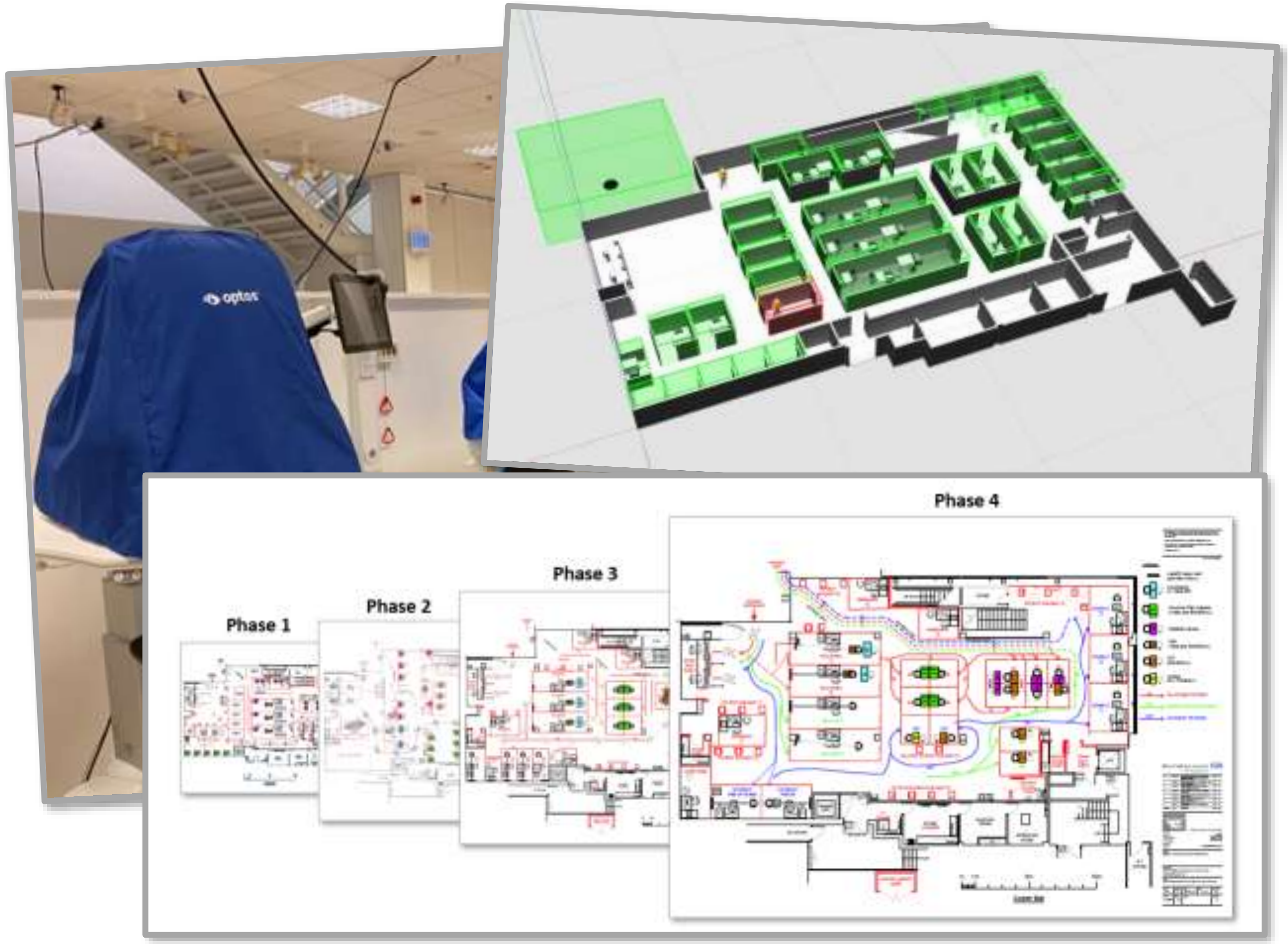
California

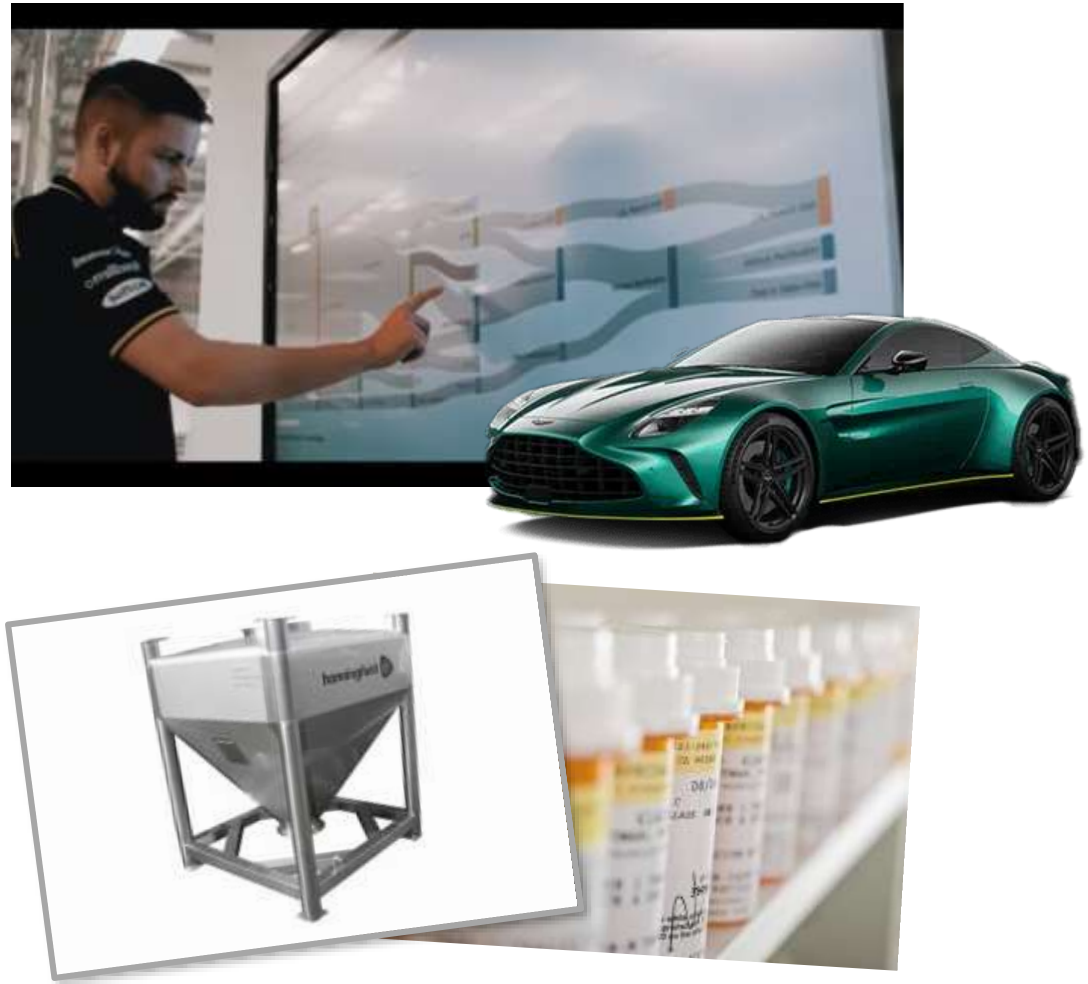
California
Military Training for Urban Combat, 2008-



UK

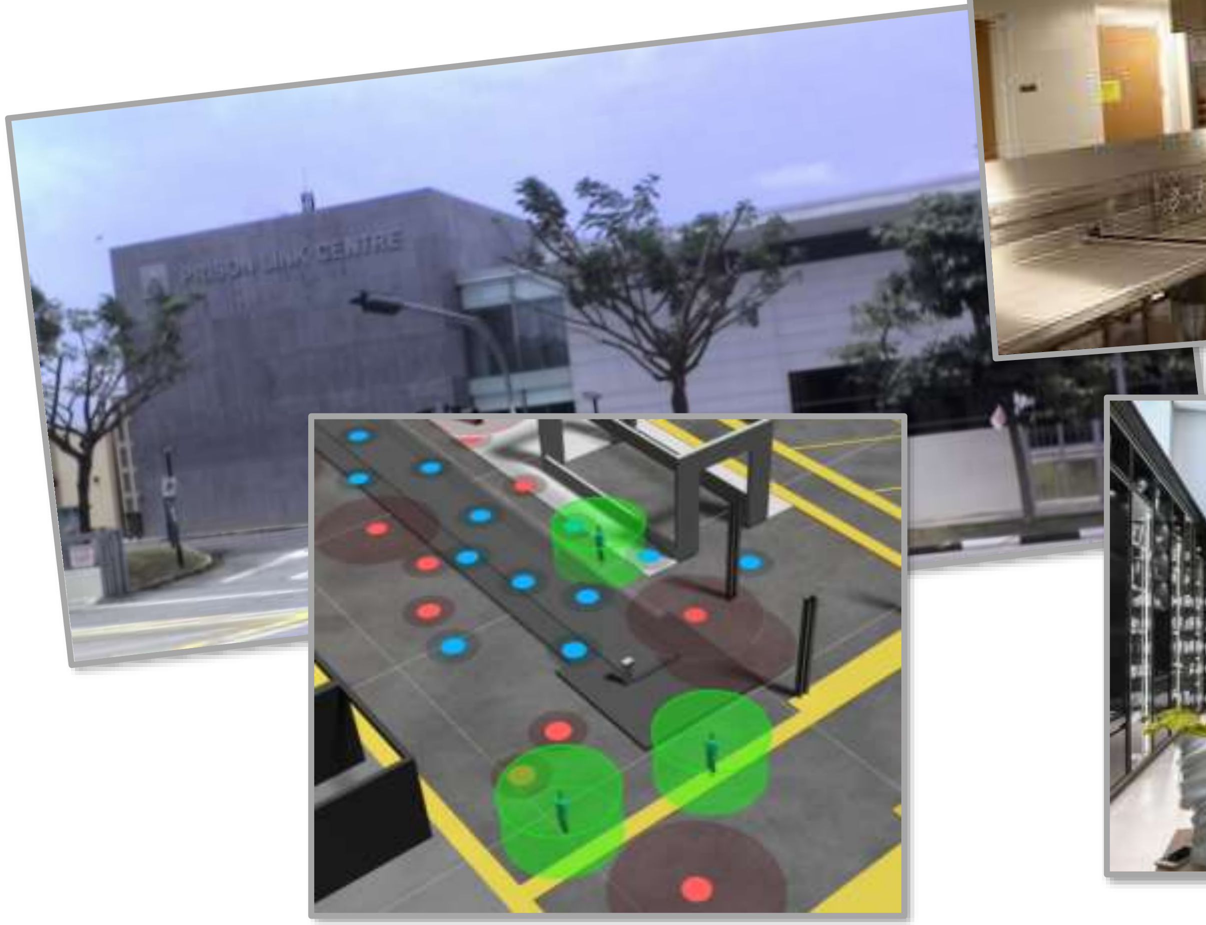
UK
Process Optimisation, Moorfields Eye Hospital (2022-)





Singapore

Singapore
Activity Analysis (2011)



Hawaii

Conclusion - there's definitely a place for indoor location

- Ubisense has focused on industrial / commercial / military applications
  - Naturally more infrastructure-tolerant than consumer applications
  - These application spaces tend to have certain requirements that are well-met by UWB:
    - Operation in GNSS-denied environments
    - High accuracy/reliability
    - Long battery lifetime
  - Other use cases may well benefit from different indoor location technologies

- These use cases are delivering real value
  - Applications are sticky - some have been in widespread use now for 15+ years

- The customer sites might not always be beautiful...but they are **always** interesting!

‘UWB indoor and outdoor positioning: European regulations update’

Paul Bearpark,
Head of Electronics & Software,
42T
https://42t.com

UWB regs and a beyond regs case study

12 Nov 2025

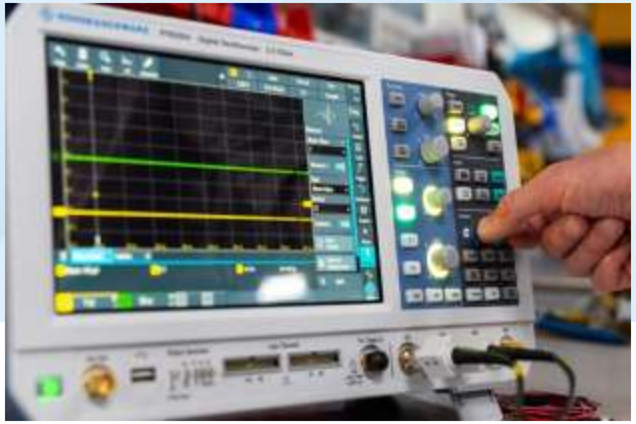
Paul Bearpark

T +44 (0)7824709153

E paul.bearpark@42T.com

UWB regulations

Part 1: UWB European regulations update
Part 2: Case study – UWB outdoor location beyond current regulations

We are 42T

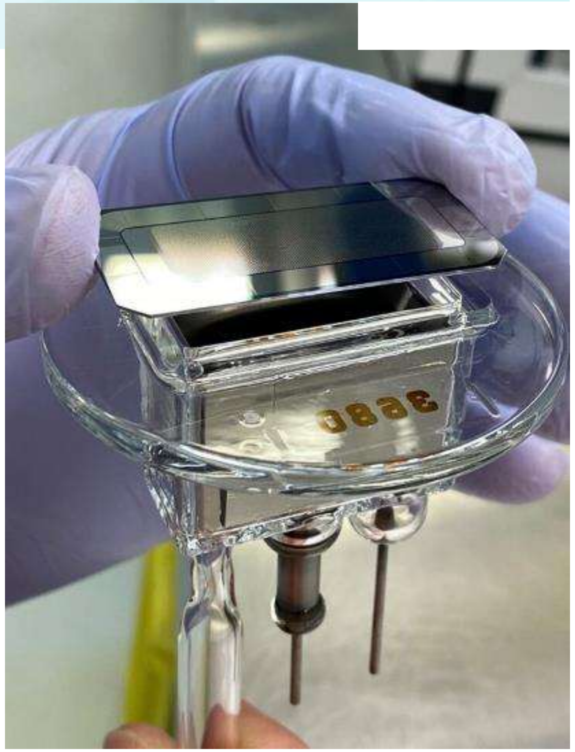
42T is a product development and innovation consultancy based near Cambridge, UK

We partner with our clients to solve complex technical problems and develop brilliantly successful products.

LRQA CERTIFIED ISO 9001

LRQA CERTIFIED ISO 13485

Ingenuity + collaboration are in our DNA



At heart we are innovators. Clients use us when:

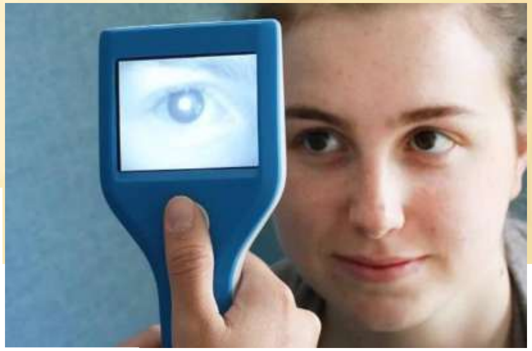
Their goals are ambitious and time-sensitive

They desire a protectable and inventive solution

They need a multi-disciplinary extension to their team

They want something technically innovative that works

We help our clients in the following areas

Design & Ethnography

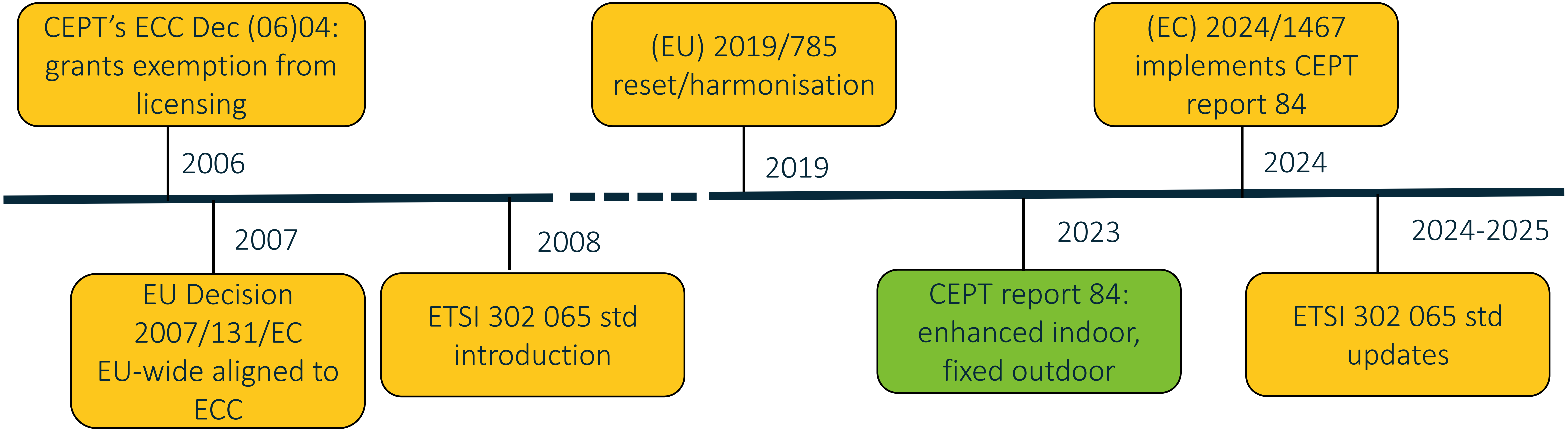
Innovation & Intellectual Property

Product Development

Manufacturing & Automation

Technology Advice

UWB regulatory timeline



What were the main changes in 2024 (6<f≤8/5GHz)?

'Enhanced' Indoor	Fixed outdoor	Vehicular (road & rail) V2I and V2V
Max mean e.i.r.p -31.3dBm/MHz Peak power 10dBm in 50MHz	Max mean e.i.r.p -41.3dBm/MHz Peak power 0dBm in 50MHz	Max mean e.i.r.p -41.3dBm/MHz Peak power 0dBm in 50MHz
	Max antenna height 10m Above 2.5m max is -46.3dBm/MHz and antennas directive and down tilted.	Antennas max height: Fixed – 10m (directive and down tilted) Vehicle – 4m
	Omnidirectional antennas for data acquisition and access control only	
Max duty cycle 5% per second	Max duty cycle 5% per second	Duty cycle max per second: Fixed – 5% Vehicle – 1%
Network/controlled operation		

What's not changed?

Generic (UWB)	In vehicle (road and rail)	Vehicle access
3.1<f≤4.8GHz -41.3dBm/MHz using LDC[1] or DAA[1]	3.1<f≤9GHz Combinations of LDC, DAA, TPC and e.l.[2] are required differently in different parts of the band	3.1<f≤4.2GHz -41.3dBm/MHz with trigger-before-transmit and LDC (≤0.5% in 1 hr)
6<f≤8.5GHz -41.3dBm/MHz (as per LT1)		6<f≤8.5GHz -41.3dBm/MHz with trigger-before-transmit and LDC (≤0.5% in 1 hr) or TPC
8.5<f≤9GHz -41.3dBm/MHz using DAA[1] (as per LT1)		No e.l. requirement Trigger by user or by the vehicle

[1] details for LDC, TPC and DAA are in ETSI 302065
[2] e.l. is exterior limit which is also defined in ETSI 302065

Also, some use onboard aircraft allowed 6.0<f≤6.65GHz and 6.6752<f≤8.5GHz
LT1 – location tracking systems type 1

Other not legally binding, non-harmonised recommendations from CEPT ECC

LT1 (as per (EC) 2024/1467)	LT2 (ECC Rec (11)09)	LAES (ECC Rec (11)10)
6<f≤8.5GHz -41.3dBm/MHz (as per LT1)	3.4-4.8GHz -41.3dBm/MHz (0dBm/50MHz max peak e.i.r.p)	3.4-4.2GHz -21.3dBm/MHz (20dBm/50MHz max peak e.i.r.p)
8.5<f≤9GHz -41.3dBm/MHz using DAA[1] (as per LT1)	Intended for person and object tracking at fixed locations either indoor or outdoor	Intended for Location tracking Application for Emergency and disaster Situations
	Max duty cycle 5% per second and max T_{on} = 25ms	Max duty cycle 5% per second
	Subject to registration and authorisation, co-ordination with victim receivers	
	To some extent superseded by recent changes to outdoor albeit at a different frequency band	

UWB new regs

Rationale for changes

Indoor RTLS – more robust signalling, greater range between devices making systems more cost effective and reliable

Outdoor RTLS – supplementing and/or lower cost than RTK systems

Pressure to maintain EU competitiveness, particularly vs US, but increases risk of interference with fixed services (FS) and fixed satellite services (FSS)

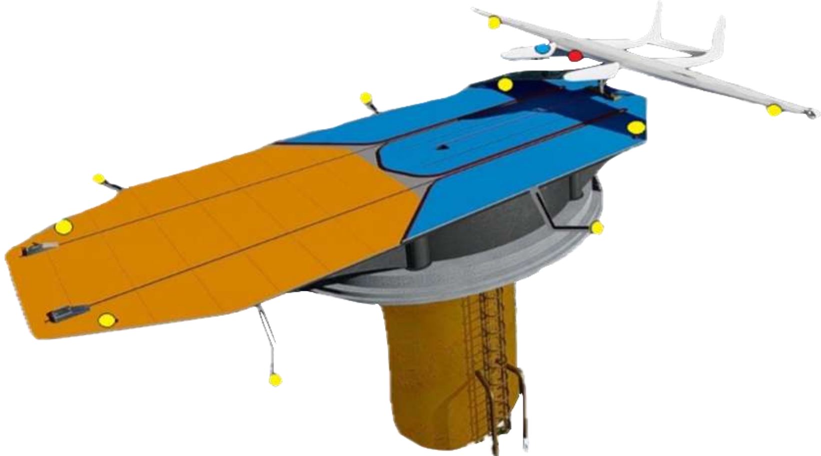
Other rationale for decision – fewer high data rate comms services appeared than anticipated. WiFi dominates. Therefore, additional scope for UWB location devices operating at higher power.

UWB is more accurate than other RF PNT technologies

Beyond the new regulations

DroneHome Objective

To develop a high accuracy, high reliability, long range, low cost autonomous navigation solution that is accurate enough to allow precise landing on both ground and elevated landing platforms, even in case of GNSS outages.



Case Study - Drone Home

ESA NAVISP2 sponsored (UKSA supported) project for which which 42T provided consultancy to Omnisense.

Ampyx Power (NL) sought an autonomous drone landing solution even under GNSS denied conditions

Adaptation of Omnisense UWB local positioning system – particularly the need for extended range – through hardware, firmware, one way communications, antenna choice

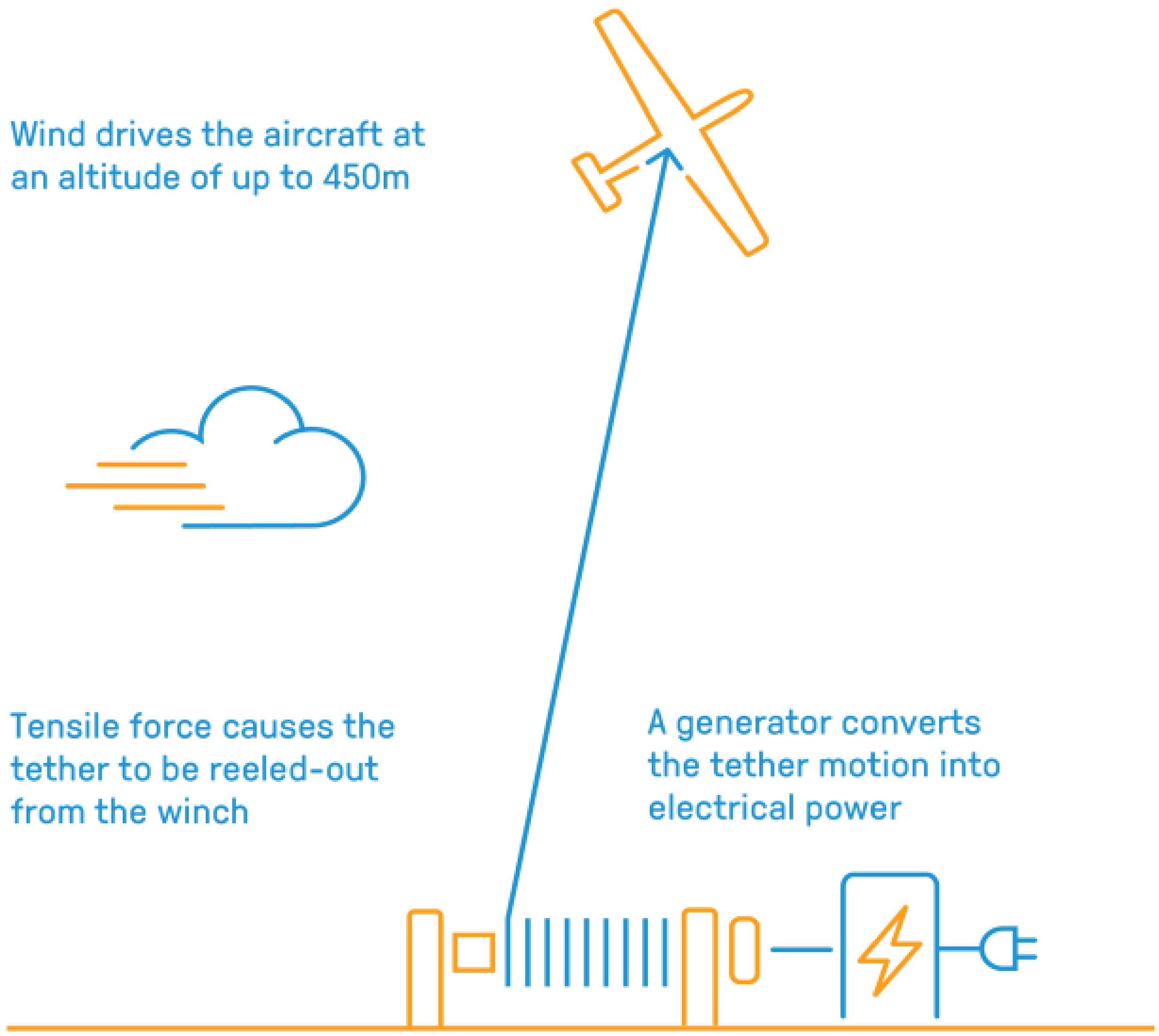
Case Study

2 phases – DroneHome 1 in 2020-22 suspended at 85% complete when prime contractor Ampyx Power (NL) closed suddenly, and then Dronehome2 in 2025 with Omnisense prime contractor

DroneHome 2 verification trials summer 2025, final review next month (Dec 2025)

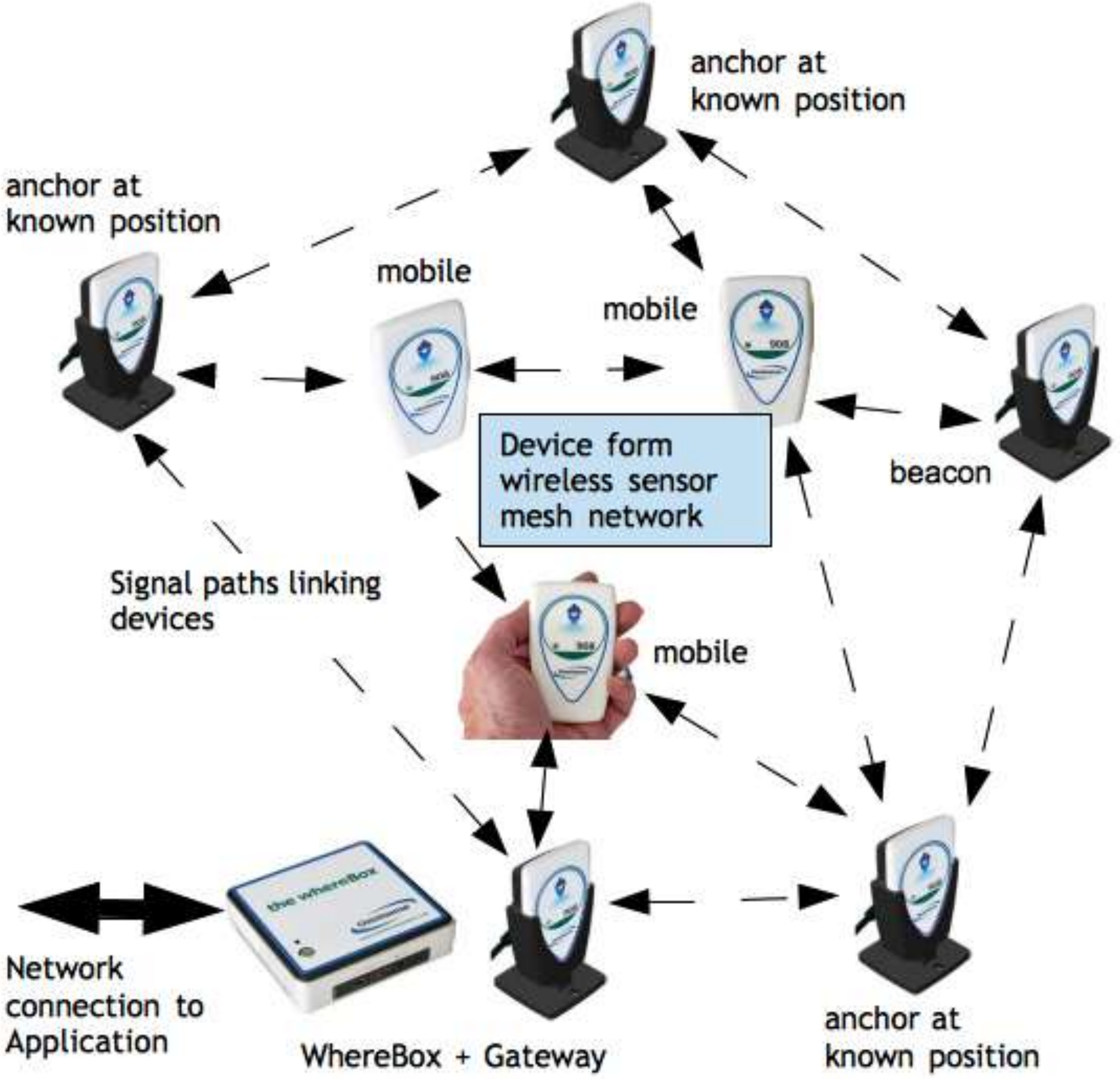
Solution will benefit from changes in UWB regulation to permit use for specific applications.

DroneHome AWES System



Omnisense LPS and DroneHome

Omnisense



DroneHome and UWB Regulations in 2022

- UWB used on a ‘non-interference and non-protected basis’ means that no harmful interference may be caused to any radiocommunication service
- UWB airborne transmission is not allowed
- Equipment used outdoors cannot be attached to a fixed installation, a fixed infrastructure, or a fixed outdoor antenna.
- Unlicenced limits the Max Mean Spectral Density -41.3dBm/MHz

EU Category	Licencing	EIRP dBm/MHz	Fixed Infrastructure	Example Report Separation
Generic UWB	Unlicenced	-41.3	No	n/a
Location Tracking Systems (LT2)	Individual Authorisation (per deployment)	-41.3 (Low Duty Cycle) -70.0 >4.8GHz	Allowed outdoor	To FS – case by case To FSS – 2.6Km
Location Tracking Emergency and Disaster (LAES)	Yes. Services or Agencies responsible for Public Safety	-21.3 (3.4 to 4.2GHz) -70.0 >4.8GHz	Expected mobile/portable and temporary outdoors	To FSS 20Km/12.3Km

Created a white paper outlining the findings above and the requirements for LPS in AWE to work with Regulators

UWB Range

Configuration	Range	LNA Gain dB	Antenna Gain dBi	EIRP Ground dBm/MHz
Unmodified Tag	9.8m	0	-5	-41.3
External Antenna (Current)	40m	0	0	-39.0
AP3 Scenario 1	200m	3	3.5	-28.5*
AP3 Scenario 2	200m	3	9	-34.0*

assumes 3dB link margin

EIRP vs Regulatory Limits

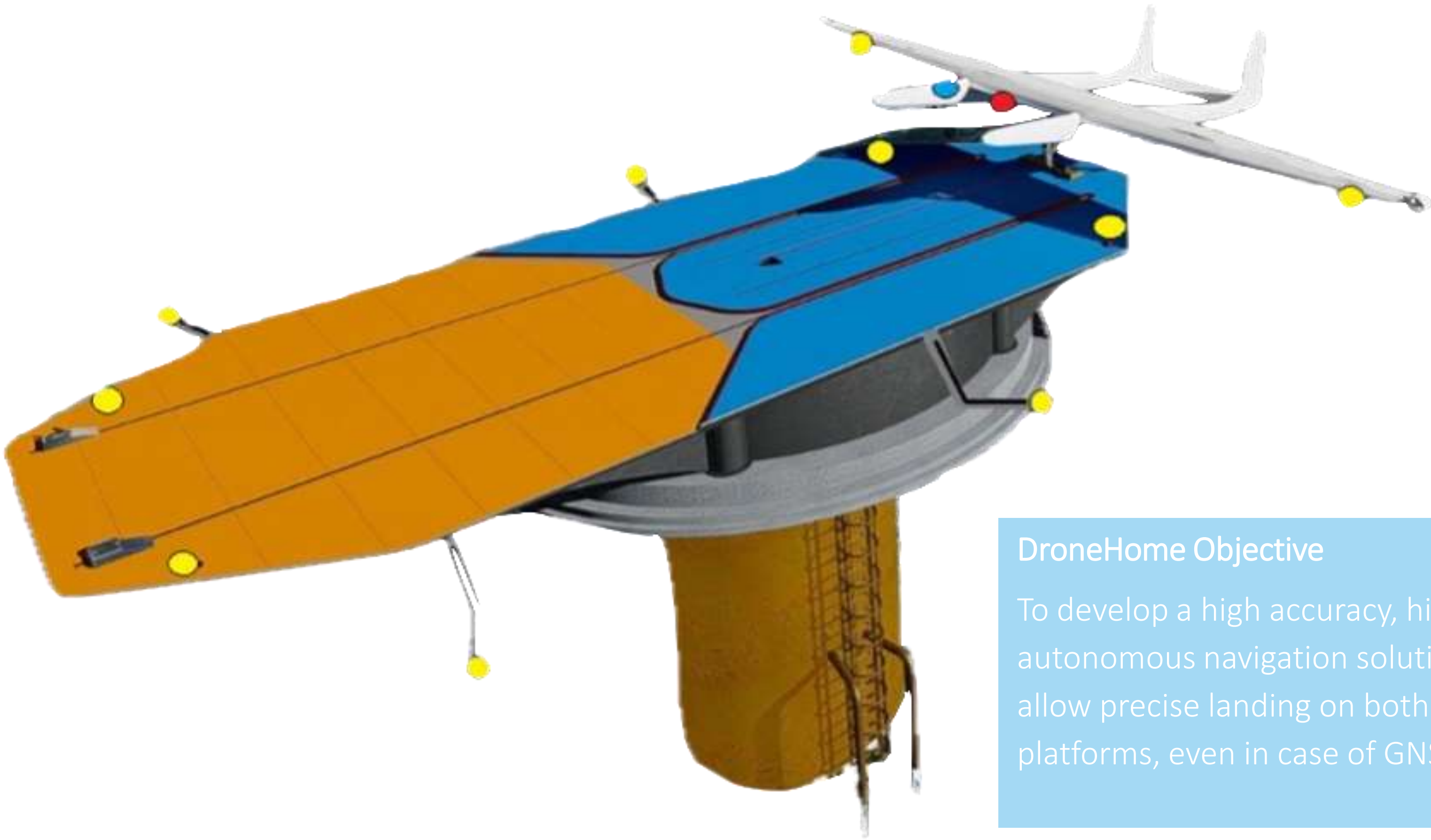
Blade type antenna

Directional antenna

- The DW1000 solution includes a feature called Smart Power. Smart TX power control only applies at the 6.8 Mbps data rate.
- When sending short data frames at this rate (and providing that the frame transmission rate is < 1 frame per millisecond) it is possible to increase the transmit power and still remain within regulatory power limits, which are typically specified as average power per millisecond.
- The achieved gain in transmit power depends on the Preamble Length, SFD length and Frame Length.

Optimise DW Smart power use

Goal – autonomous landing on raised platform



DroneHome Objective

To develop a high accuracy, high reliability, long range, low cost autonomous navigation solution that is accurate enough to allow precise landing on both ground and elevated landing platforms, even in case of GNSS outages.

GCN535 with LNA and PA

UWB Internal Antenna

UWB PA/LNA switch

Low Noise Amplifier (LNA)

UWB Antenna Switch

UWB Internal Antenna

Power Amplifier (PA)

PPS Interrupt

42T.

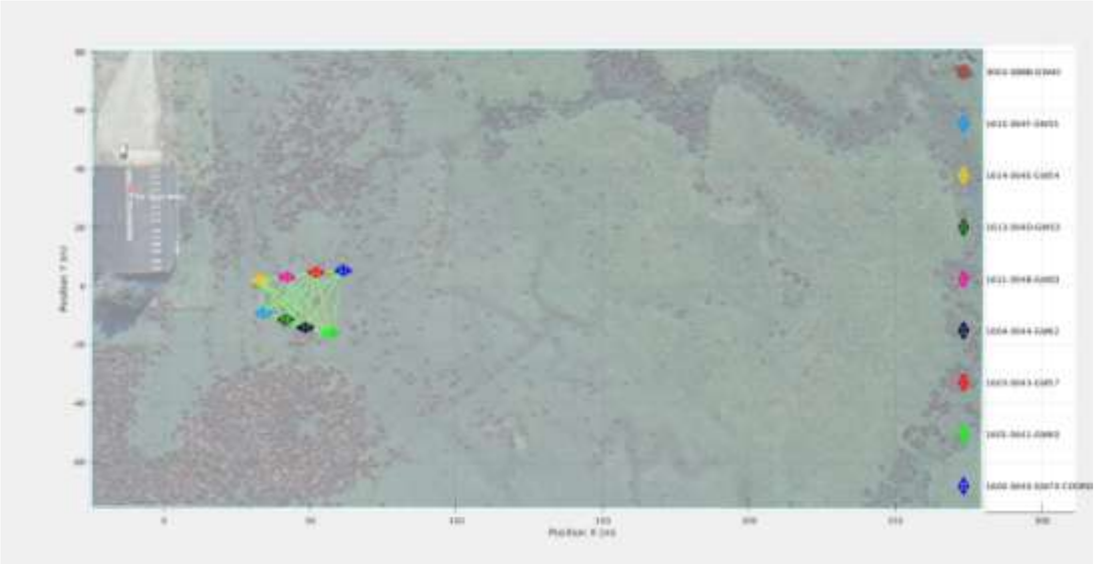
Omnisense

Field Testing

Verification Testing
Wrafton, Devon
July 2025

2 month licence granted by Ofcom to operate UWB at higher power at test site

Drive and Flight Tests

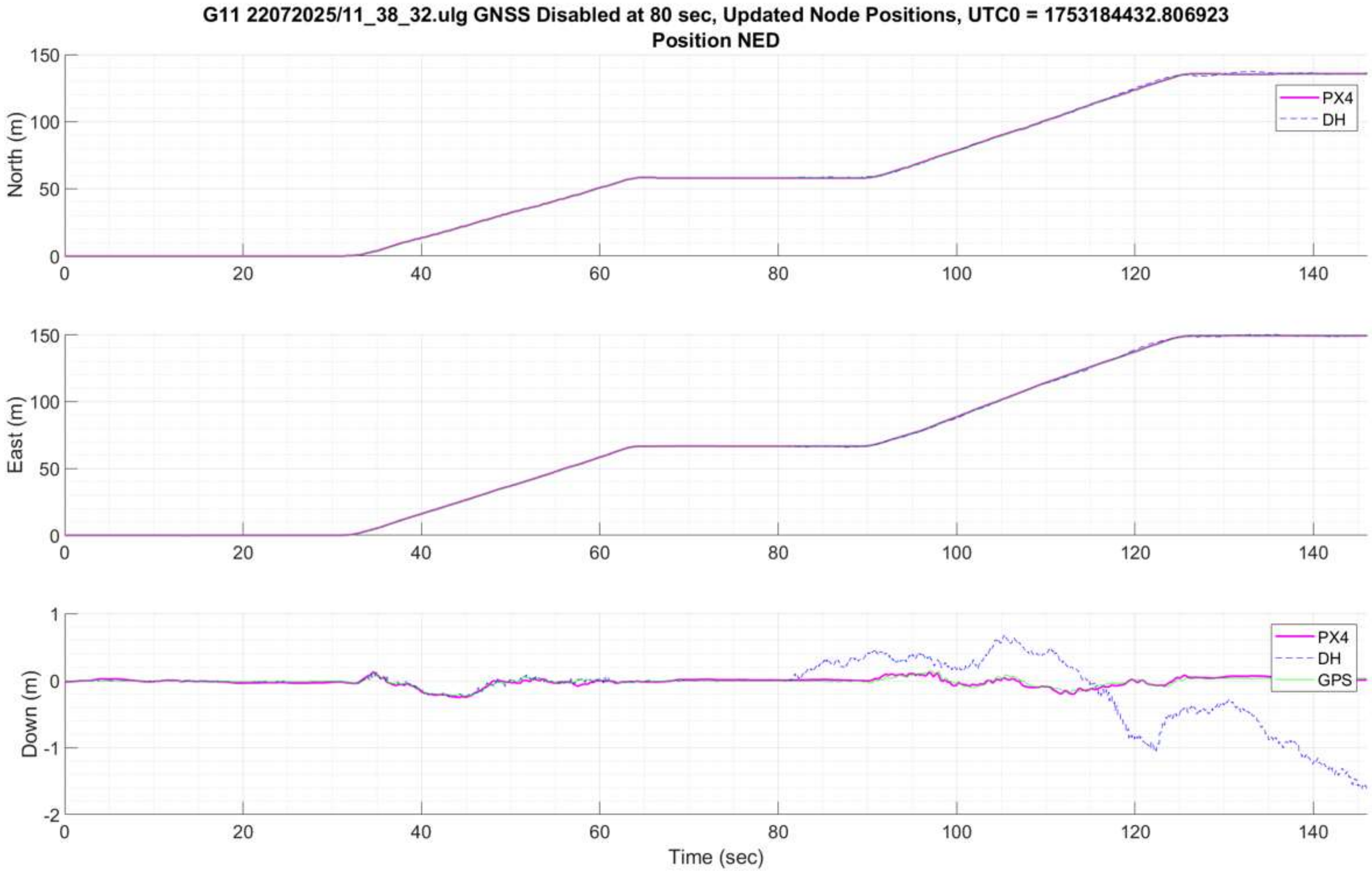


Array of Fixed Beacons approached by receive only tag on Mounted Drone

Lat/Lon of replayed solution compared to PX4 navigation solution. G11-GNSS Denial.

Correlation of GNSS and IMU enabled track from navigation engine of Pixhawk 4 Drone alongside integrated DroneHome LPS solution following GNSS removal, i.e. modelling of capability for GNSS denied landing

NED Positions during approach (XYZ)



Key points to take away

- Relaxation of regulations has created new opportunities for both indoor and outdoor UWB applications
- The fixed outdoor was a surprise in a way (to me) but probably reflects the fact the UWB has not become ubiquitous in the way that WiFi has
- Given the very low use in rural areas there may be a case for higher power for infrequent use and when geolocated
- The DroneHome application is good example of a use case:
  - Support for landing of drones when GNSS is compromised
  - And/or increased landing reliability working in conjunction with GNSS

Briteyellow

Fredi Nonyelu

Founder & CEO

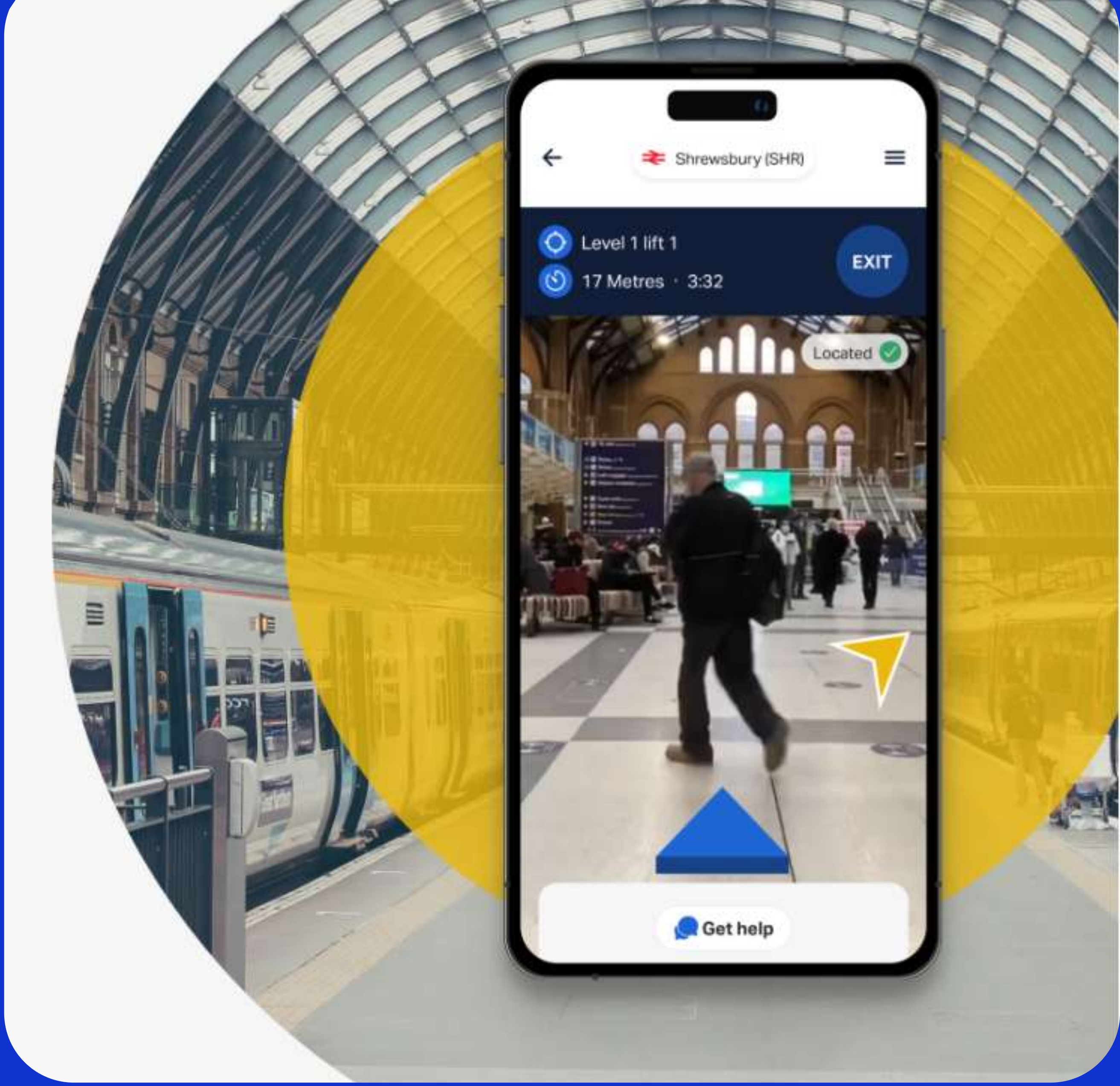
Briteyellow

www.briteyellow.com

briteyellow

Pioneering spatial Intelligence

Indoor positioning and navigation for complex built environments



Presented by Fredi Nonyelu

briteyellow

Agenda

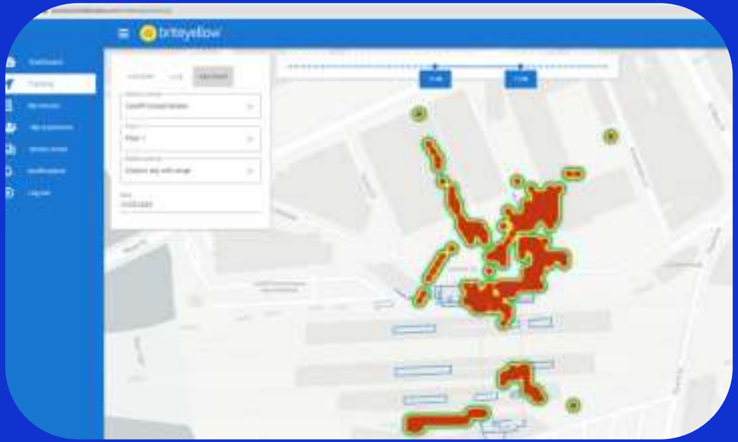
Topics Covered

1. **Who are we:** Briteyellow at a Glance
2. **Problems we solve:** For older and disabled people
3. **Our solution:** Spatial Intelligence Platform
4. **Applications:** Real world

briteyellow

Briteyellow at a glance

Managed WiFi 2003-2012



Position Tracking 2012-2019

Spatial Intelligence 2020-2025

briteyellow

Inaccessible Journeys

1 in 4 disabled people avoid travel

due to navigation barriers.

briteyellow

Unsafe Care

> 57% of UK carers suffering burnout

due to staff shortage

briteyellow

Spatial Intelligence platform

Enabling more accessible journeys and prioritised care for older and disabled people, and increased efficiency for operators.

briteyellow

Real World Applications

Briteway

Travel Companion App

£47k/yr staff efficiency savings

Britecare

Virtual Care Assistant

28% increase in staff efficiency

Britezone

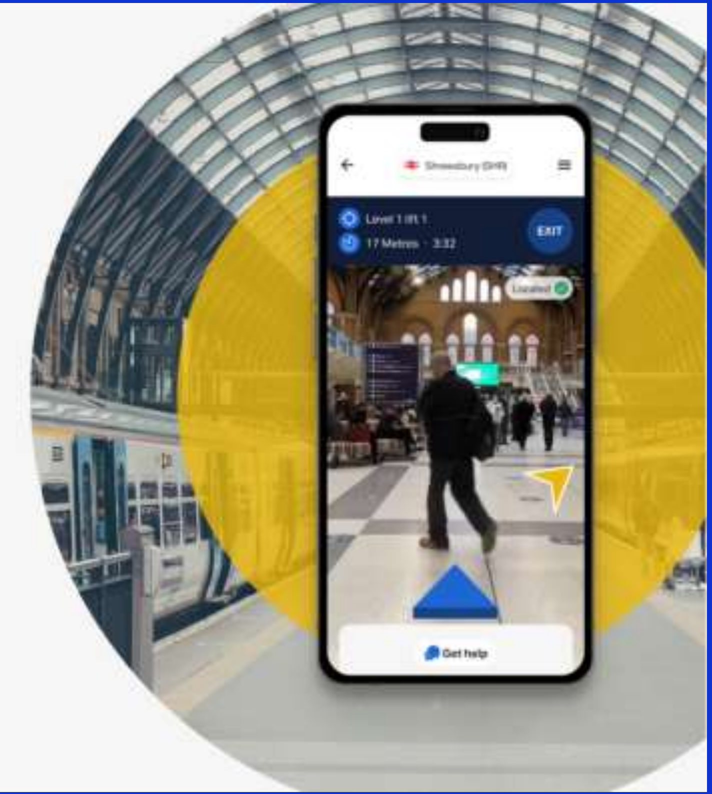
Spatial Insights Dashboard

Unlock hidden efficiencies & opportunities

briteyellow

Thank you!

Turning complex buildings into smart places.



For more info, visit briteyellow.com
fredi.nonyelu@briteyellow.com.

Waymap

Jon Stone
Head of Location Technology,
Waymap

www.waymapnav.com

Waymap x Indoor Positioning

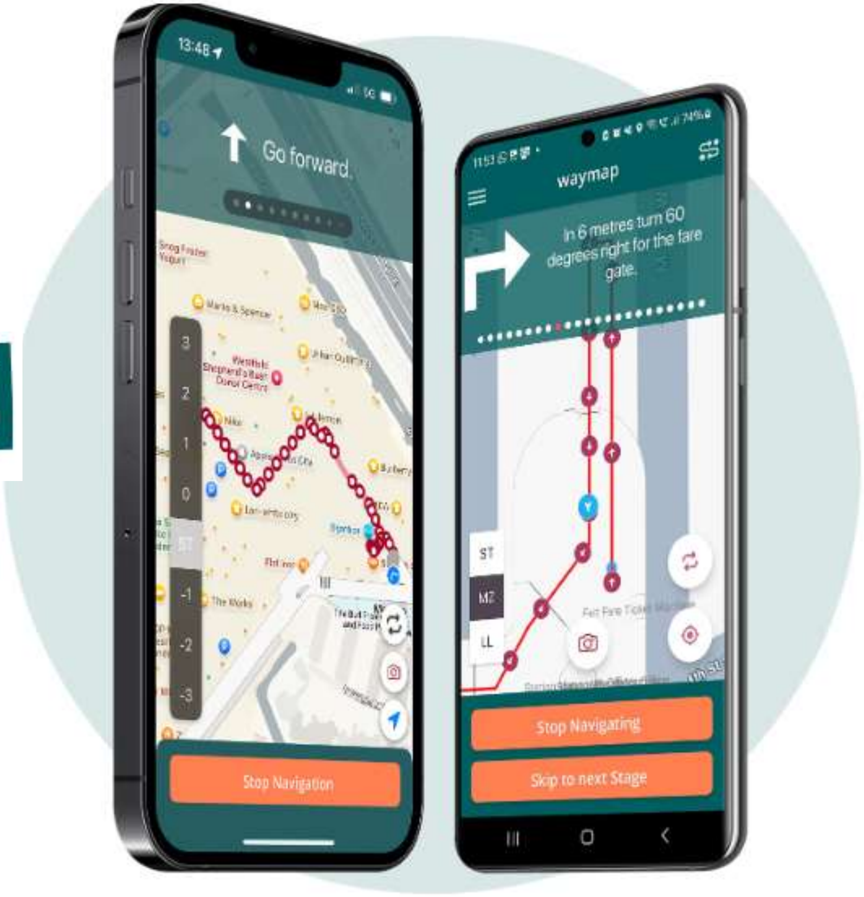
This is where we are....

The Only Navigation App That Works

Outdoors Indoors Deep Underground

Whether navigating you directly to your underground platform, around a shopping centre or on and off your bus, this is the world's most precise navigation app.

Book a Call



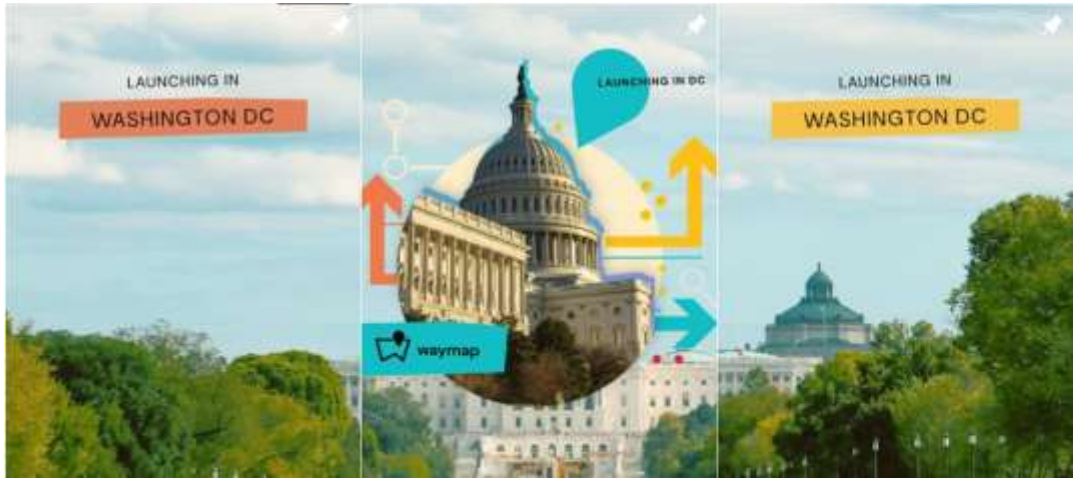
Accessibility at Scale…

Our Reach

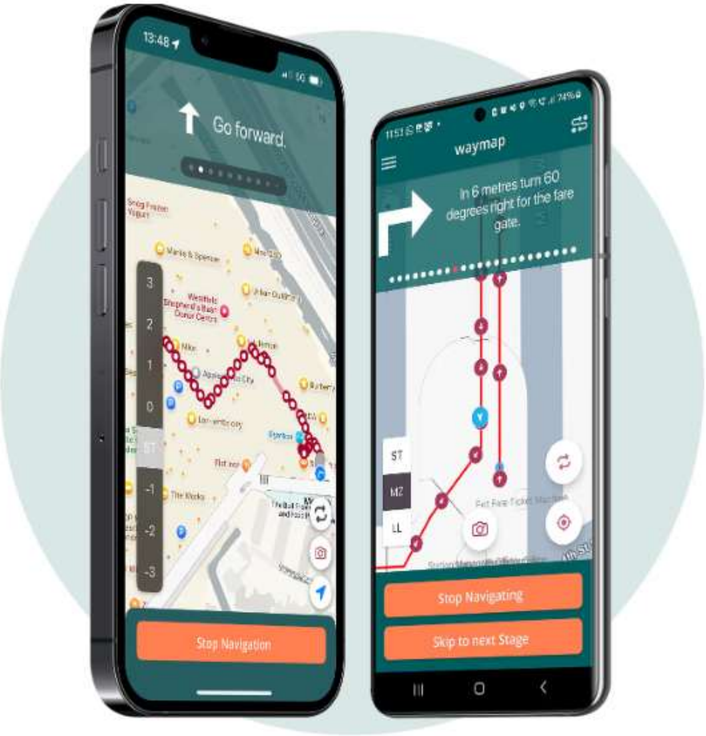
1 Billion+
Sq. Feet Mapped

140+
Locations

10+
Cities



Cutting-edge navigation tech…



How Waymap Guides Every Journey

Efficient and personalized journey planning, with real-time step-by-step instructions.

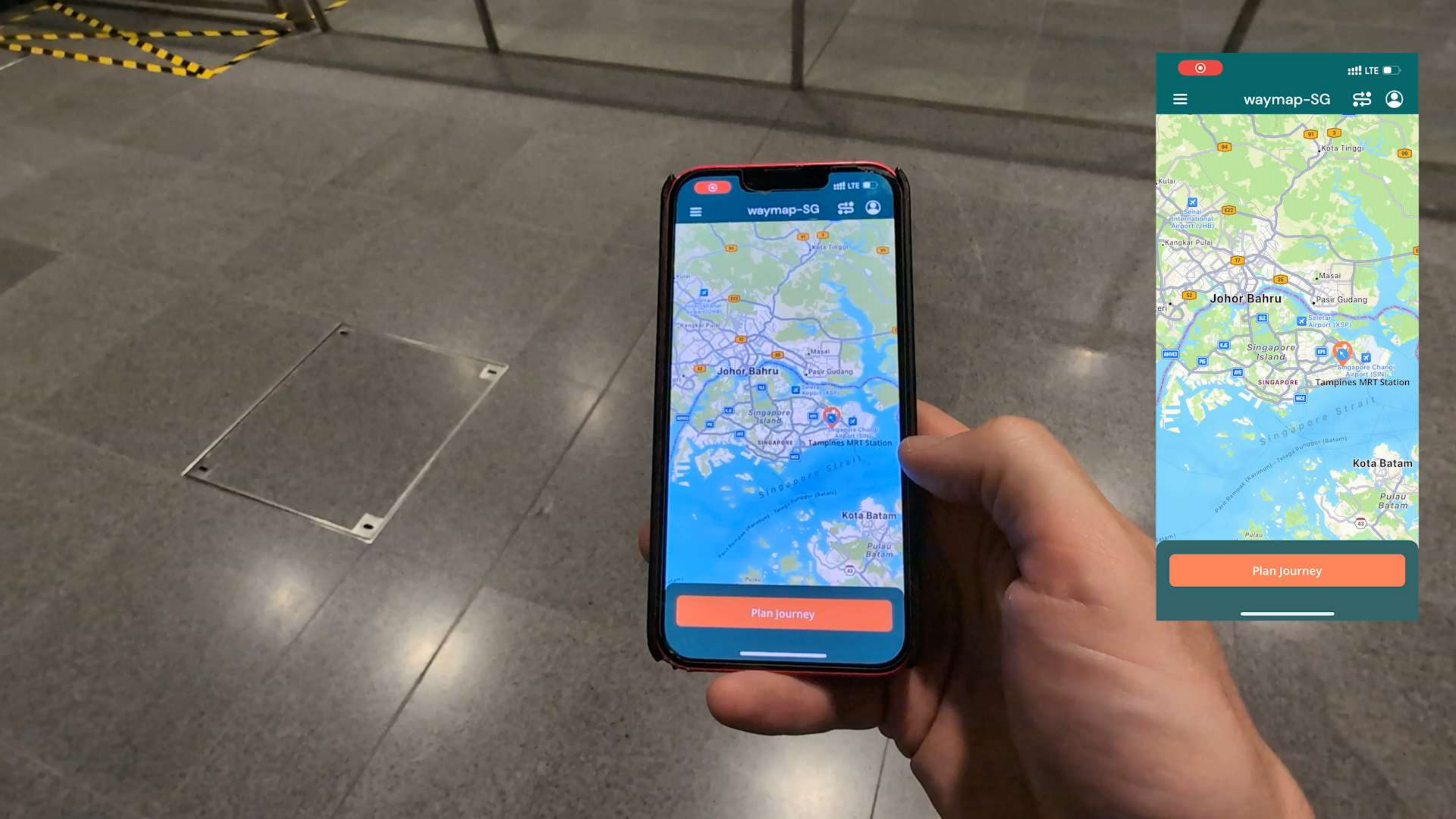
SmartStep™

Novel Location Engine

Advanced sensor fusion algorithm, that doesn't require GPS, Bluetooth, mobile data or Wifi

Visual Positioning System

Low latency camera-based positioning, locating users to centimetre-level accuracy


LTE
waymap-SG
Kota Tinggi
Kulai
Senai International Airport (JHB)
Kangkar Pulai
Masai
Johor Bahru
Pasir Gudang
Seletar Airport (XSP)
Singapore Island
SINGAPORE
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Thanks!

‘Using Bluetooth Channel Sounding to improve indoor positioning’

Mayank Batra,

Principal Engineer, Qualcomm Technologies International, Ltd.

www.qualcomm.com

Qualcomm

Using *Bluetooth®* Channel Sounding to improve Indoor Positioning

Mayank Batra,
Principal Engineer,
Bluetooth Standards Lead

Agenda

- Evolution of Bluetooth positioning
- What is Bluetooth Channel Sounding?
- Core principles
- How phase-based ranging works
- How round-trip time works
- Security measures
- Conclusions

Evolution of Bluetooth positioning

Bluetooth LE (2010): Enabled presence detection and basic item finding (Find Me Profile).

Beacons & RSSI (2013): First-generation distance estimation using signal strength (TX Power & RSSI).

Direction Finding (2019): Bluetooth SIG introduced Angle of Arrival (AoA) and Angle of Departure (AoD) for direction calculation using phase measurements and antenna arrays.

Channel Sounding (2024): Next step for accurate, secure distance measurement.

Limitations of Previous Methods

RSSI-based distance estimation not accurate enough for many applications.

No indication of direction or robust security safeguards.

Direction finding improved accuracy but still had limitations for fine-ranging.

What is Bluetooth Channel Sounding?

- A new feature in the Bluetooth Core Specification enabling secure, accurate distance measurements between Bluetooth devices.
  - Fundamentally, it enables a device to characterize the propagation path to a remote device.
  - Released as part of Bluetooth Core Specification 6.0* in August 2024. Enhancements already being developed.
- Designed to improve accuracy and security in device positioning applications.
  - Line of sight: ± 50 cm accuracy for distances up to 5 meters, ± 10% of actual distance for higher distances.
  - Multiple antennas can be used on one or both devices to counter the effects of multi-path indoors.
- Use cases:
  - Find My solutions: More accurate item location.
  - Digital keys: Enhanced security for access control.
  - Asset tracking & navigation: Reliable, fine-grained positioning.
  - Developer flexibility: Prioritize accuracy, security, or latency as needed.
    - Can enable distance measurements typically at 10 Hz (one measurement every 100 milliseconds).
- Limitation: A point-to-point connection is required between the two devices.

* https://www.bluetooth.com/specifications/specs/core-specification-6-0/

Core principles

Radio wave properties: amplitude, wavelength, frequency, phase.

Two main methods:

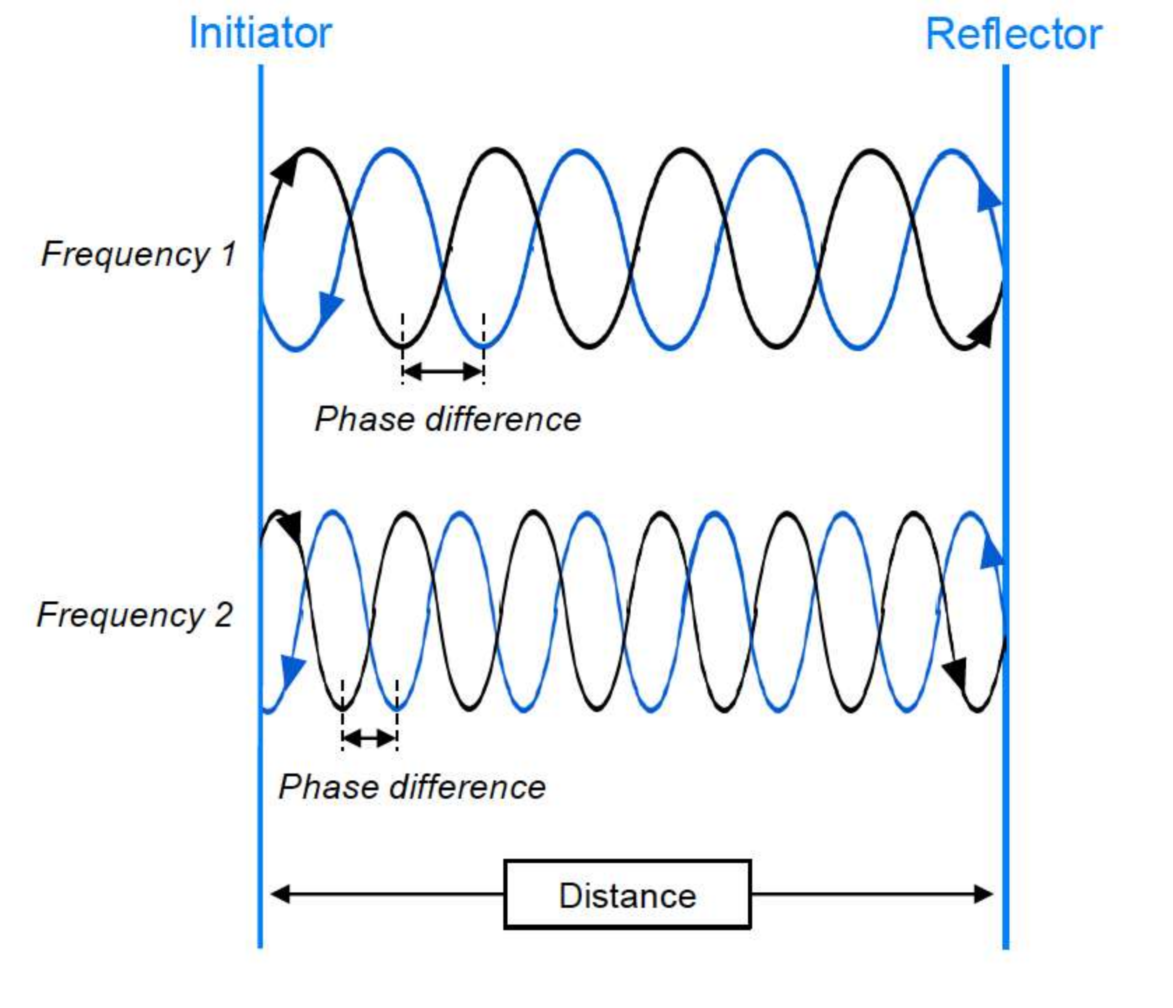
Phase-Based Ranging (PBR): Measures phase differences across frequencies to calculate distance.

Round-Trip Time (RTT): Measures time-of-flight for signals between devices. Also provides different levels of security.

Both PBR and RTT supported; PBR is primary for accuracy, RTT adds security and resolves ambiguity.

How Phase-based Ranging works

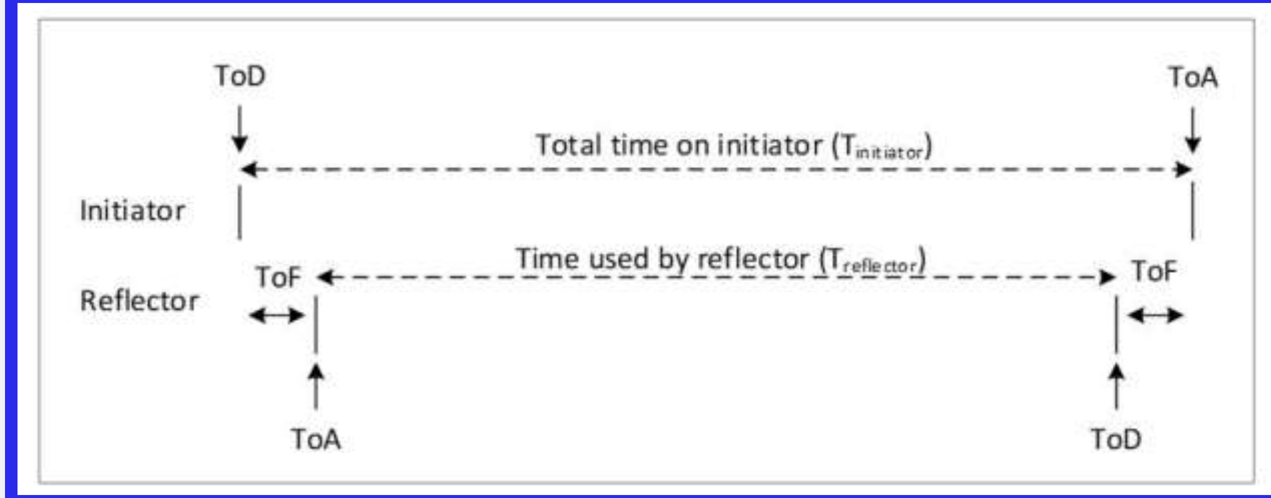
- Frequency f1:
  - Initiator sends a tone at frequency f1.
  - Reflector performs a phase measurement.
  - Reflector sends a tone at frequency f1, calculates PCT*.
  - Initiator performs a phase measurement, calculates PCT.
- Reflector sends its PCTs to Initiator.
- Total phase shift $\Delta\phi$ is the sum of two PCTs.
  - $distance = c \times \Delta\phi / 4\pi \times f$
- To resolve phase ambiguity (wrap every 2π), tones are exchanged at multiple frequencies.
- Slope of phase vs. frequency gives a linear estimate of distance.
- Ambiguity can arise due to periodic phase values; RTT helps resolve this.



* Phase Correction Term: Difference between the phases of the received and transmitted tones

How Round-Trip Time works

- Measures time taken for a signal to travel from Initiator to Reflector and back.
- Reflector sends its ToD – ToA measurements to Initiator.
- Distance = $((T_{initiator} - T_{reflector})/2) \times c$.
- Requires precise timestamping and compensation for device processing delays.



Security features

- RTT with Sounding or Random Sequence
  - Mitigate replay attacks and timing-based exploits by introducing unpredictability in the signal pattern.
- Combined PBR & RTT:
  - Hard to attack both simultaneously. Phase and time attacks require different techniques.
- Deterministic Random Bit Generator (DRBG):
  - Generates cryptographically secure random bits for randomizing bit streams, access addresses, antenna paths.
  - Reduces predictability in patterns, making it harder for attackers to guess or inject malicious data.
- Attack detection:
  - Normalized Attack Detector Metric (NADM) to monitor anomalies in signal behavior and report likelihood of attack.
- SNR control:
  - Injects noise into the channel making it harder for attackers to extract useful information from signals.
- LE 2M BT=2.0 PHY (BT=time-bandwidth product in GFSK):
  - Improves physical layer security by making it harder for an attacker to inject a fake signal without matching exact waveform.

Conclusions

- Previous positioning methods were less reliable:
  - RSSI-based distance estimation could be affected by environmental factors, leading to variability in accuracy.
    - Also impacted by variations in TX output power (±2 dB) and variations in RSSI accuracy (±2 dB) leading to uncertainty.
  - Typically confirmed presence, not precise location/direction; performance could degrade with obstacles/signal attenuation.
  - Direction finding (AoA/AoD) improved accuracy but still faced challenges with fine-ranging and robust security.

- Channel Sounding: A notable improvement in reliability
  - Uses phase-based ranging and round-trip timing to deliver more accurate distance measurements
  - Reduces (but does not entire eliminate) the impact of RSSI limitations and multipath effects.
  - Built-in security features (randomization, attack detection, SNR control) to help protect against spoofing and relay attacks.

- Indoor positioning revolution:
  - In challenging indoor environments, Channel Sounding enables more precise, secure, and reliable location determination.
  - Enables new applications for navigation, asset management, and “Find My” solutions in offices, hospitals, airports, etc.

Thank you

Nothing in these materials is an offer to sell any of the components or devices referenced herein.

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Indoor Positioning: Where are we?

This event is delivered by the Cambridge Wireless Location SIG

CAMBRIDGE WIRELESS

In partnership with The Royal Institute of Navigation

ROYAL INSTITUTE OF NAVIGATION

Kindly hosted by Queens' College, Cambridge

QUEENS' COLLEGE CAMBRIDGE

Agenda

Niki Trigoni, Navenio & Tamzin Lent, WhereYouAt (WAY) - No longer able to join us

13:50 **Paul Groves, University College London (UCL)** - 'Positioning Indoors and Outdoors'
Q&A

14:15 Bullet presentations:

- **Dr Richard Hoptroff** - 'Lessons from the Outdoor Position, Navigation and Time community'
- **Marianne Slamich, CMO, Pointr**

14:25 **Chris Steer, Geoptic** - 'Advances in Applied Muon Positioning'
Q&A

15: 00 Event ends

‘Positioning Indoors and Outdoors’

Paul Groves,

Professor of Positioning and Navigation,

University College London (UCL)

www.ucl.ac.uk

Positioning Indoors and Outdoors

Paul D Groves
Professor of Positioning and Navigation
University College London
p.groves@ucl.ac.uk

Indoor Positioning: Where are we?
Cambridge, 12 November 2025

UCL ENGINEERING
Change the world

Robust Positioning and Navigation at UCL

Vision

A world where a real-time low-cost position solution within 3m is available in all places at all times

Mission

- To improve the reliability of navigation and positioning technology in challenging environments
- To devise, develop and demonstrate new methods of navigation and positioning
- To optimize the integration of different navigation technologies embracing the challenges of complexity, context and ambiguity
- To educate people about navigation technology

Current and Recent Projects

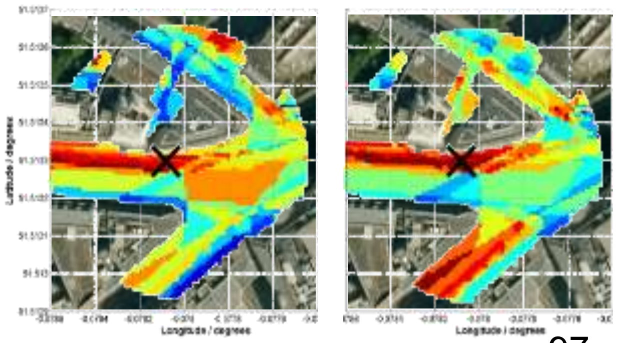
- Wi-Fi Round Trip Timing – Indoor
- Foot Mounted Inertial Navigation – Outdoor
- Semantic Visual Feature Matching – Outdoor
- Magnetic Anomaly Matching – Indoor
- 3D Mapping Aided GNSS – Outdoor
- Navigation Doppler Lidar for Aircraft Navigation – Outdoor
  Collaboration with Curtin University, Australia











The Great Positioning Divide

Indoors

- Wi-Fi
- Localisation
- Sensor Hybridization
- Computer Science
- IPIN

Outdoors

- GNSS
- Navigation
- Sensor Integration
- Engineering
- ENC, ION

BUT

- Most journeys are both outdoors and indoors
- Radio signals do not stop at building boundaries (Faraday cages excepted)
- The basic principles of positioning are the same everywhere
  - Ranging
  - Angulation
  - Feature matching
  - Motion sensing

Does GNSS Work Indoors?

6-35 satellites received

4-38 satellites received

2-25 satellites received

1-15 satellites received

- Relatively weak 15-25 dB-Hz
- More signals and stronger signals on higher floors
- More signals and stronger signals nearer to Windows

Answer: GNSS works in many buildings

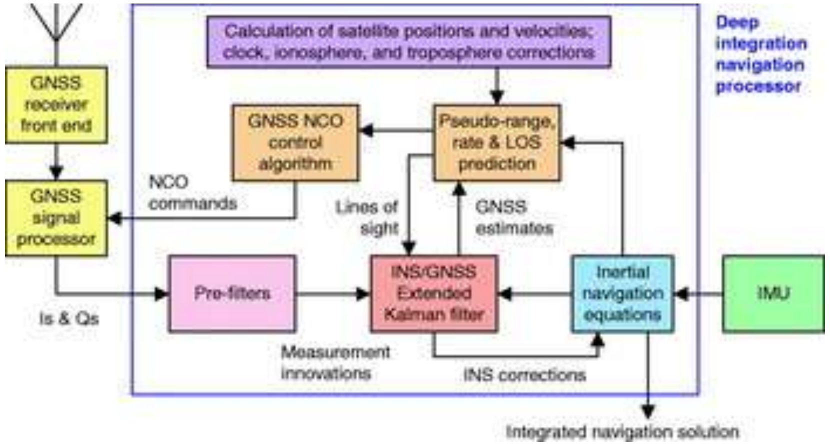
BUT: Not all, and it’s generally less accurate than outdoors

Results from Mengxin Wei MSc project report, UCL, 2023

Can Indoor GNSS be Improved?

Receiver sensitivity can be boosted using inertial sensors to provide it with motion information

- Known as deeply-coupled integration, ultra-tight-coupling, synthetic aperture GNSS and supercorrelation
- Boosts sensitivity by 10 dB or more
- Originally a military technology
- Now adapted to work with consumer-grade chips and sensors – Ublox X20
- Gives better availability and accuracy indoors



Low Earth Orbit (LEO) satellites

- Much stronger signal ~20 dB
- More satellites needed
- Several proposals under development

Image: Eutelsat OneWeb

Does Wi-Fi Fingerprinting Work Outdoors?

Results from Humza Hussein MSc project report, UCL, 2024

4.1 m

5.3 m

2.2 m

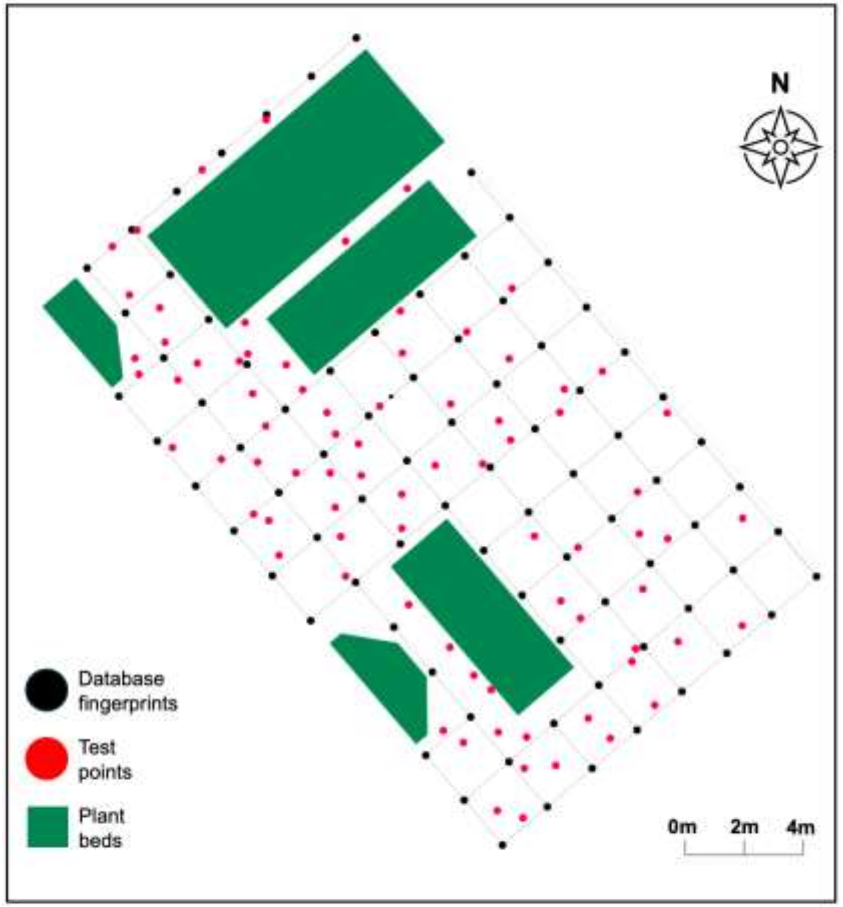
3.8 m

3.4 m

3.0 m

Answer: Yes

Is Outdoor Wi-Fi Fingerprinting Practical?



From Humza Hussein MSc project report, UCL, 2024

Answer: Of Course Not!

- You can't sample a 2x2 m grid of signal strengths in the middle of a street

BUT Indoor fingerprinting is impractical too

- Building surveys are time consuming and expensive
- Cooperation of the building operator is needed

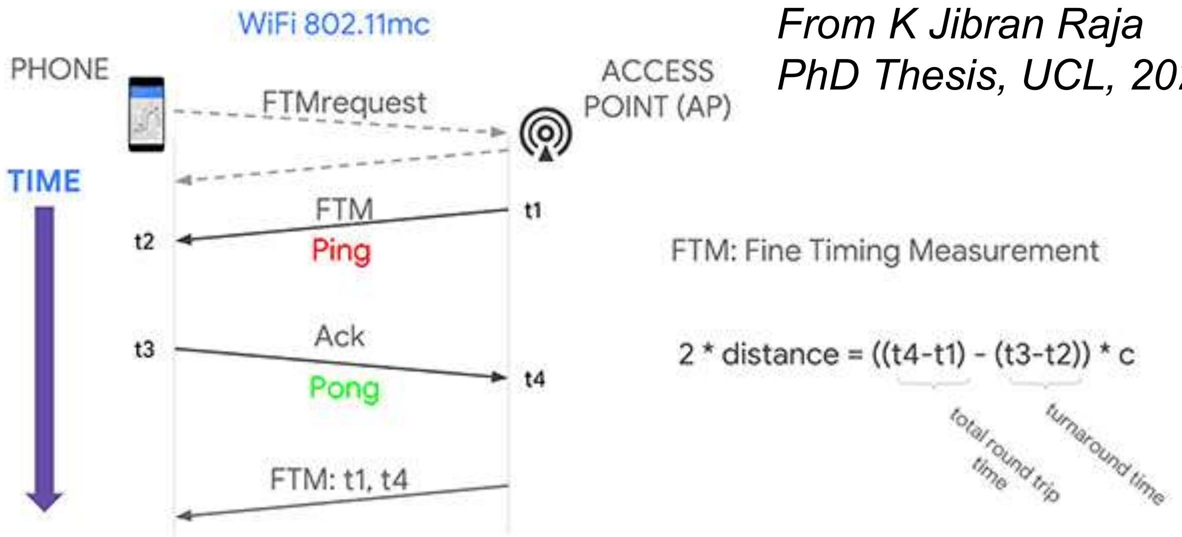
What About Wi-Fi Ranging?

Google's location service estimates range from received signal strength

- Less accurate than fingerprinting
- More practical – customer data is used to build the access point database

Round trip timing (RTT) gives more accurate range measurements from compatible access points

- UCL has achieved 2m accuracy (mainly indoors) – *K Jibran Raja PhD thesis*
- Google use Wi-Fi RTT measurements outdoors



From K Jibran Raja PhD Thesis, UCL, 2024

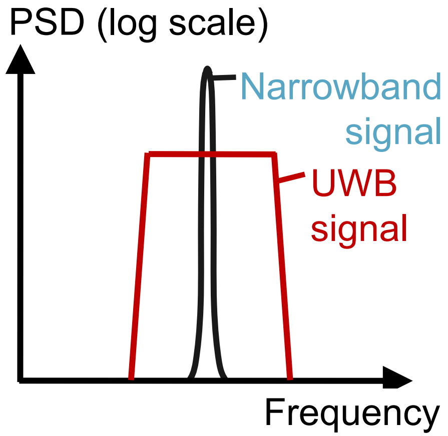
What About Other Radio Signals?

Phone Signal Positioning

- Works indoors and outdoors
- Relatively poor accuracy unless there's a clean line-of-sight to multiple base stations
- Typically used to initialize GNSS and Wi-Fi positioning

Ultrawideband

- High precision indoor positioning
- Outdoor use limited by short range of standard UWB protocols
- Range can be extended by reducing the data rate –*demonstrated by Thales circa 2008*



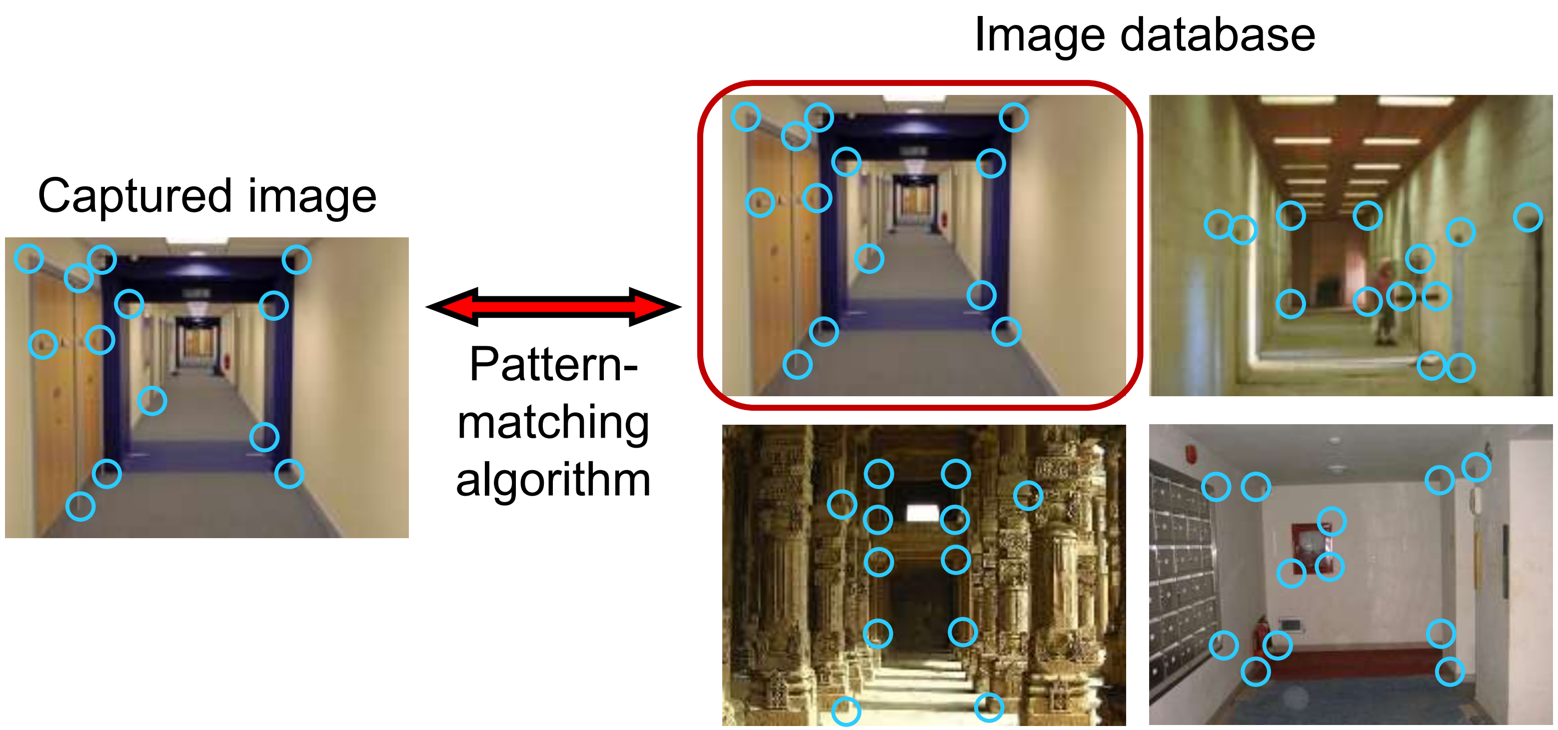
eLoran

- Designed for maritime positioning
- Adopted for time synchronisation
- Can be less accurate in cities
- Not much testing indoors

Visual Features

Image-Database Matching

- Hardware and basic principles are the same for indoors and outdoors
- Different feature descriptors may suit different environments



Cross-view Image Matching

- Sometimes we need to match a forward looking image to a map or aerial photo
- Traditional feature descriptors don't translate well
- UCL is investigating sematic segmentation

From Harrison Reeves, UCL

Magnetic Anomaly Matching

Indoors – Lots of Features

- Structural Materials
- Furniture, radiators
- Electrical equipment
- Cabling

The challenge is dealing with complexity

UCL has shown

- AC and DC fields should be treated separately
- Potential benefits of sampling at different heights

(Peter Thompson PhD thesis)

Outdoors – Features are Sparse

- Lamp posts
- Metal pillars
- Some building exteriors

Dead Reckoning (Motion Sensing)

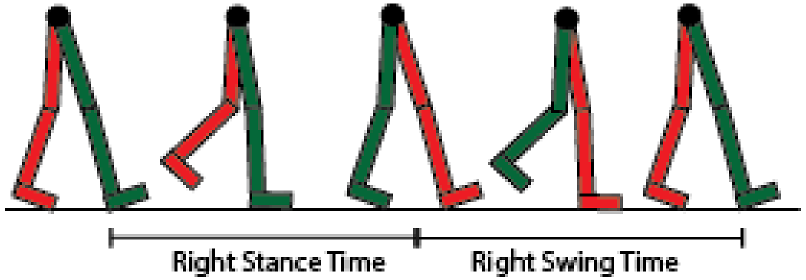
Wheel Speed Odometry

- Distance travelled estimated from wheel rotation measurement and wheel radius
- Works exactly the same indoors and outdoors
- Little difference in error characteristics

Pedestrian Dead Reckoning

- Uses inertial sensor measurements to detect steps and estimate step length
- Sensors can be placed anywhere
- Smartphone sensors typically used
- Works exactly the same indoors and outdoors

BUT – Terrain is more complex outdoors



Inertial Navigation

- Direction obtained by integrating angular rate measurements
- Distance travelled obtained by double integrating acceleration (*obtained from non-gravitational acceleration measurements & a gravity model*)
- Works the same in *any* environment
- Accuracy depends on sensor quality
- More commonly used outdoors:
  - Size
  - Weight
  - Cost
  - Power

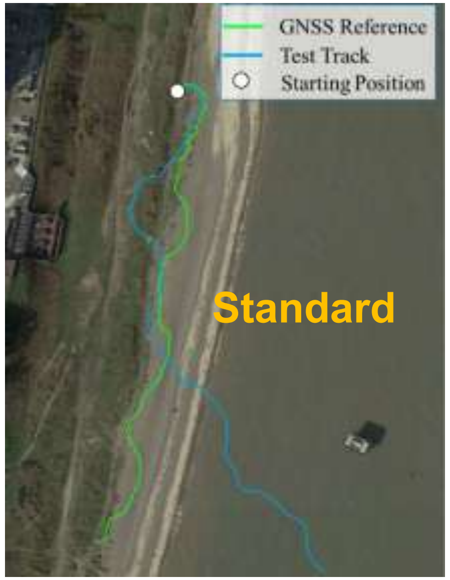
Foot-Mounted Sensors

- Zero-velocity updates each step calibrate the errors
- Accuracy ~1% of distance travelled (low-cost sensors)
- Works the same on hard terrain indoors and outdoors

BUT Outdoors, we must adapt to soft terrain

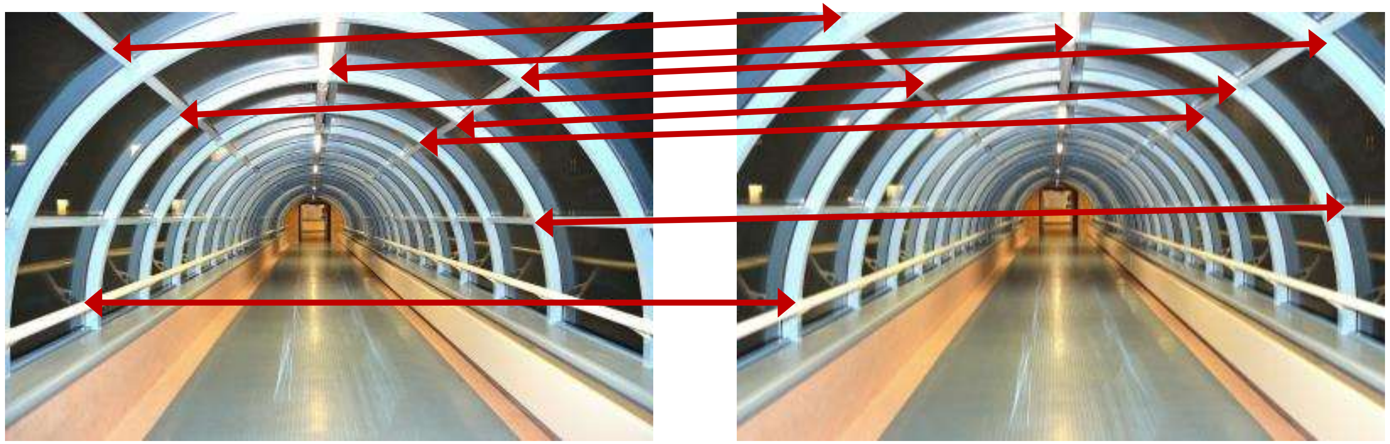
- UCL has shown that the terrain type can be detected using the IMU and machine learning

From Taylor Knuth PhD Thesis, UCL, 2025



Visual Odometry

- Features compared across successive images
- Need scale information to infer camera motion
  - Height above ground
  - Stereo camera
  - Range sensor
- Low-cost inertial sensors can aid outlier detection



- Feature descriptors can be environment-dependent
- Rural & urban more different than urban & indoor

Hardware and basic principles are the same for indoors and outdoors

- Harder to infer camera motion using more distant features

Sensor Integration

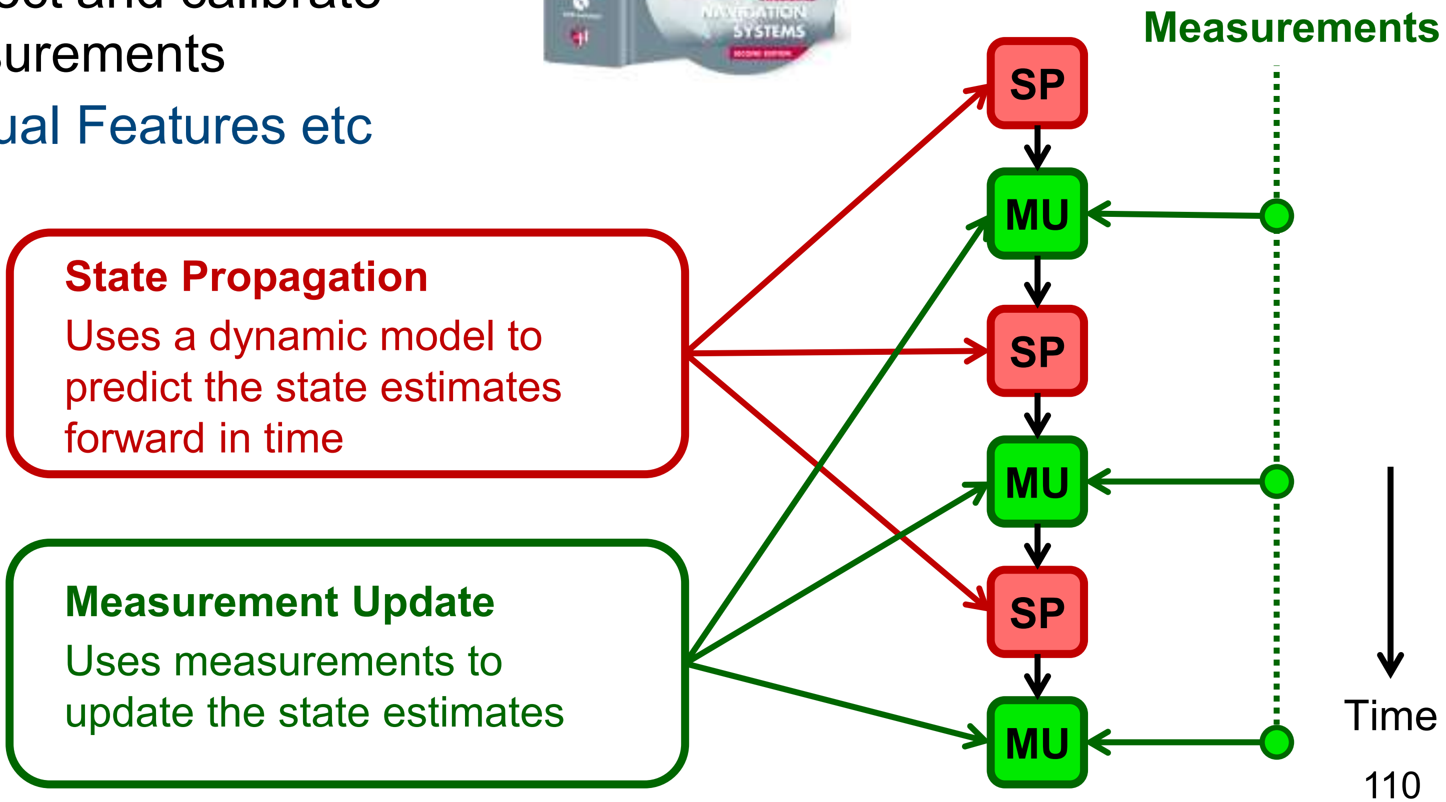
The same approach is used indoor and outdoor

- Motion sensing maintains a constant navigation solution
  - Inertial navigation, Dead reckoning, Odometry etc
- Bayesian estimation algorithms correct and calibrate this using absolute positioning measurements
  - GNSS, Wi-Fi & Other Radio, Visual Features etc

Context-adaptive integrated navigation systems

- Detect the environment
  - Indoor/ outdoor
- Detect the behavior
  - Pedestrian/ vehicle
- Adapt accordingly

See Han Gao PhD Thesis, UCL, 2018



Conclusions

- No positioning technology works exclusively indoors or exclusively outdoors
- Some technologies are more reliable or more practical indoors
- Others are more reliable or more practical outdoors
- Many positioning technologies need adapting for indoor or outdoor operation
  - No different from adapting to land, sea or air
- We should not be treating indoor and outdoor positioning as separate disciplines

‘Lessons from the Outdoor Position, Navigation and Time community’

Nancy Scott
Corporate Projects Director,
Hoptroff

www.hoptroff.com

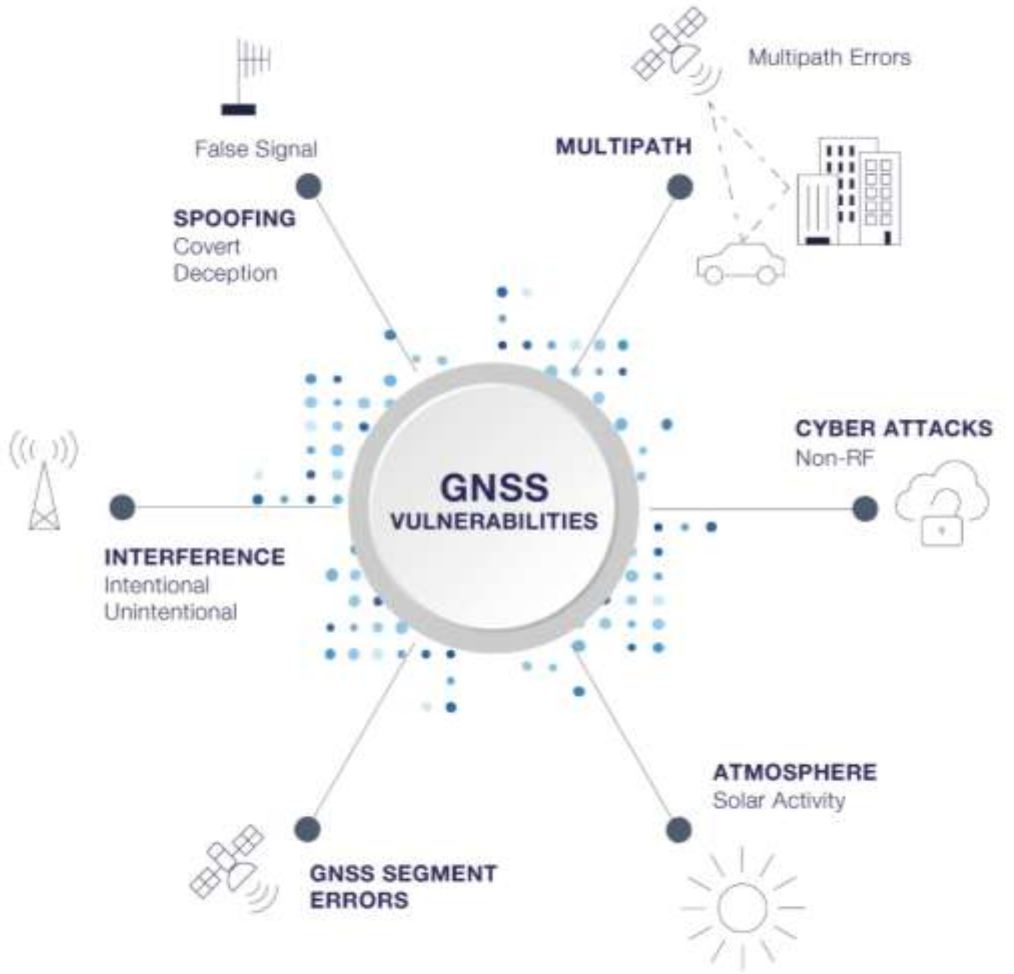
Accurate, monitored, synchronised and resilient – because without timing, nothing works

Position, Navigation and Time (PNT)

- Why do we need **Time**?
  - To create a true record of the sequence of events for data transfer
    - From financial transactions to emergency services
  - To make sure events happen in the right order for safety and data integrity for interconnected technologies
    - From power distribution, broadcast to telecommunications
- How Hoptroff does it ?

We rely too much on GNSS (e.g. GPS)

- When GNSS ceases to work, the Chain of Comparisons ceases to function and sequence of events can get broken
- Bad things happen
  - Financial market manipulation
  - Power substation failure
  - Telecommunications failure
  - Transportation fails



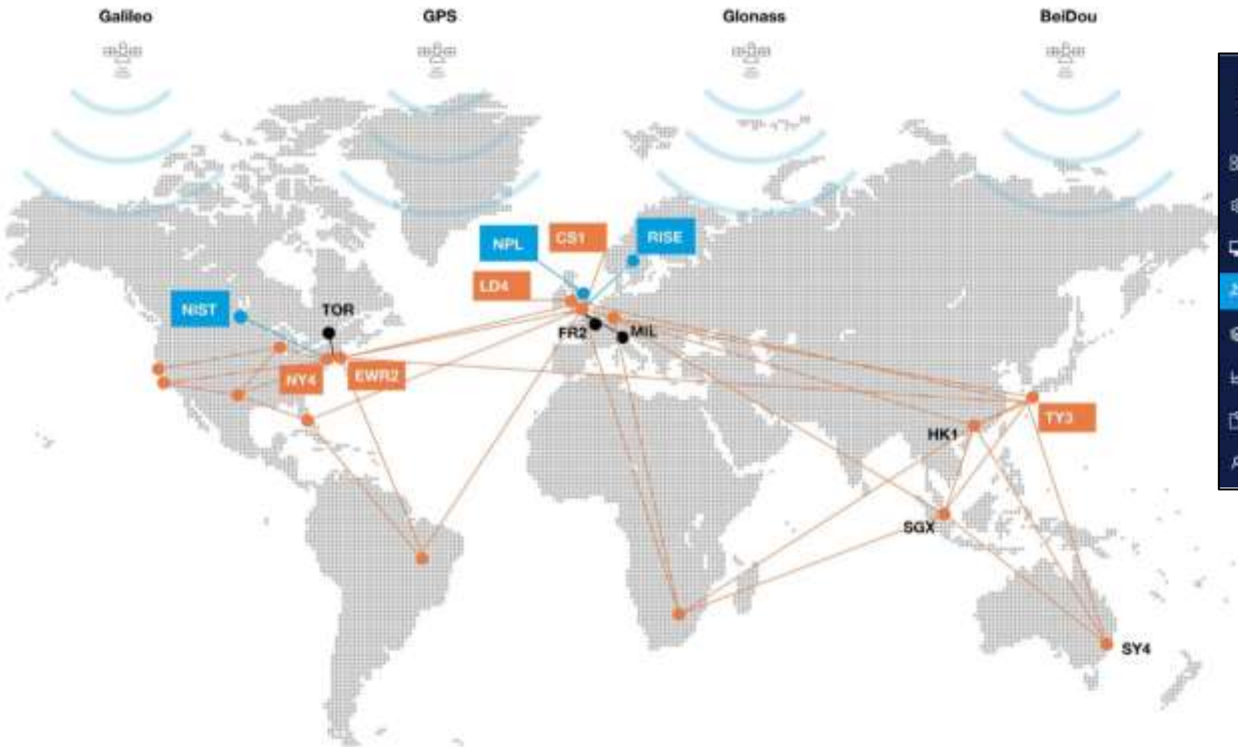
Regulations & Standards

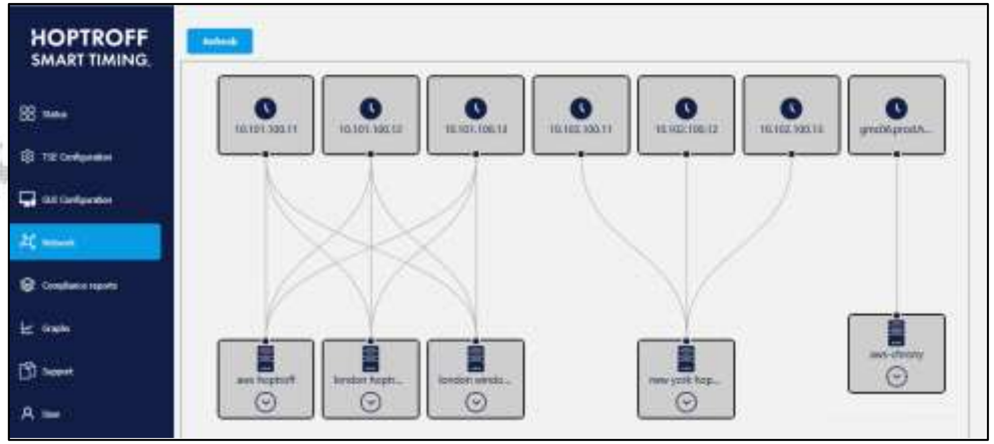
Regulation / Standard	Date	Accuracy	Sector	Intent	Geography	Traceability
IETF v4, RFC 5905 (NTP)	1985	Traceable	Engineering	System Interoperation	Global	UTC
HIPAA	1996	Traceable	Healthcare	Record of events	US	UTC
HL7	1997	1s	Healthcare	Record of events	Global	UTC
Gramm-Leach-Bliley Act (GLBA)	1999	Traceable	Finance	Security & Data Integrity	US	UTC
Sarbanes-Oxley (SOX)	2002	Traceable	Finance	Security & Data Integrity	US	UTC
IEEE 1588-2008 (PTP)	2008	Traceable	Engineering	System Interoperation	Global	UTC
FINRA CAT NMS	2012	100us	Finance	Record of events	US	UTC
IEC 61850-5 - Synchrophasors	2013	1us	Power	Measurement	Global	Relative
IEC 61850-5 - Fault Recording	2013	100us	Power	Measurement	Global	UTC
IEC 61850-5 - Transient Events	2013	1ms	Power	Measurement	Global	UTC
IEC 61850-5 - Power Quality	2013	10ms	Power	Measurement	Global	UTC
IEC 61850-5 - Slow Events	2013	100ms	Power	Measurement	Global	UTC
EENA NG112	2013	1ms	Emergency Services	Record of events	EU	UTC
JCAHO/JCI EHRPI (Q) 482.24(c)(1)	2013	Traceable	Healthcare	Record of events	Global	UTC
IOSCO FR04/13	2013	By country	Finance	Record of events	Global	UTC
MiFID II	2014	100us	Finance	Record of events	EU	UTC
21 CFR Part 11	2014	Traceable	Food & Drug	Record of events	US	UTC
NENA STA-026.5-2022	2016	100ms	Emergency Services	Record of events	US	UTC
EU Annex 11	2016	Traceable	Food & Drug	Record of events	EU	UTC
SMPTE 2110 / SMPTE 2059-2	2017	1us	Broadcast & Media	System Interoperation	Global	Relative
ITU-T G826x LTE/5G-NR FDD - Frequency Generation	2018	50 PPB	Telecoms	System Interoperation	Global	Relative
JT-NM TR1001-1	2019	100ms	Broadcast & Media	System Interoperation	US	UTC
ITU-T G827x LTE/5G-NR/eMBMS - TDD Slot Alignment	2019	10us	Telecoms	System Interoperation	Global	UTC
ITU-T G827x LTE/5G-NR TDD - Carrier Alignment	2019	1us	Telecoms	System Interoperation	Global	UTC
ITU-T G827x LTE/5G-NR TDD/eCIC- Interference Management	2019	1us	Telecoms	System Interoperation	Global	UTC
ITU-T G827x LTE/5G-NR TDD CoMP/LBS - Cell coordination	2019	1us	Telecoms	System Interoperation	Global	Relative
US Exec Order 13905	2020	Traceable	Critical Infrastructure	GNSS Resilience	US	UTC
ISO27001 / ISO27002 / ISO17799	2022	Traceable	Enterprise	Security & Data Integrity	Global	UTC
PCI-DSS 10.4	2022	Traceable	Card Payments	Record of events	Global	UTC
NIS2 OPS1.1.5.A4	2022	Traceable	Critical Infrastructure	Cybersecurity	EU	UTC
DORA	2023	Traceable	Finance	Security & Data Integrity	EU	UTC
UK Risk Register	2023	Traceable	Critical Infrastructure	GNSS Resilience	UK	UTC
CFTC 17 CFR 23.202	2024	1m	Finance	Record of events	US	UTC
RIS-6702-DST Appendix F	2024	Not specified	Rail	Signalling & control	UK	UTC
NENA STA-026.5-2022	2025	100ms	Emergency Services	Record of events	US	UTC
EU notice 9188/1/25	2025	Not Specified	Critical Infrastructure	GNSS Resilience	EU	UTC

Hoptroff's Time Sync Solution

Hoptroff provides global time dissemination from multiple timescales across the globe, with terrestrial connectivity to National Measurement Institutes including **NPLTime** and NIST. Long distance time delivery is achieved through a mix of close relations with telecoms companies and smart NTP and PTP client software.

- Many enterprise customers worldwide, from finance to defense. **99% of applications are indoor.**





HOPTROFF
SMART TIMING™

Keeping the world on time

Nancy Scott
Corporate Projects Director
Nancy.scott@hoptroff.com

hoptroff.com

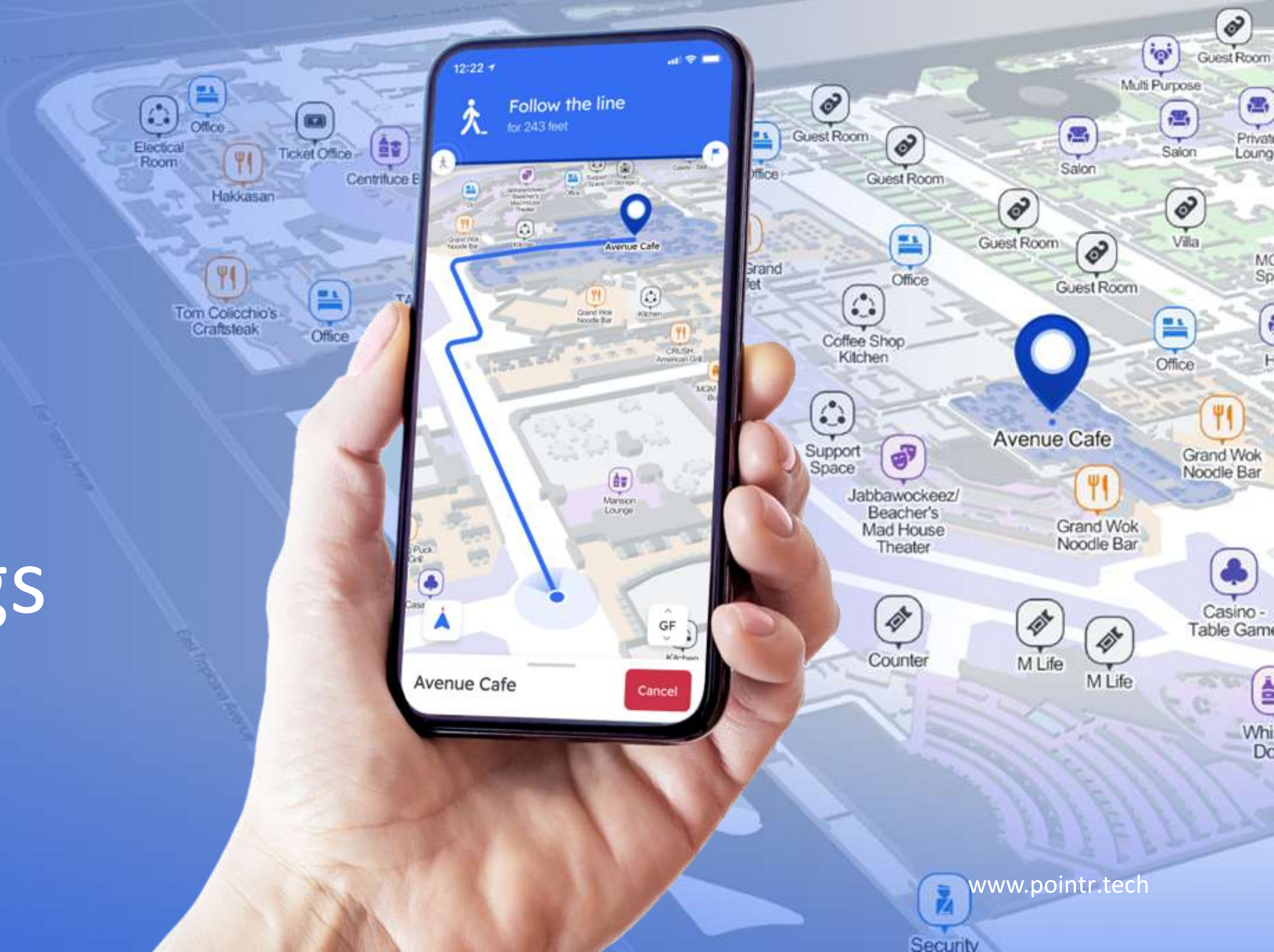
With acknowledgement to https://www.nlai.blue

Pointr

Marianne Slamich
CMO
Pointr
www.pointr.tech

November 2025

Indoor Location
for Smart Buildings



Pointr

www.pointr.tech

Problem

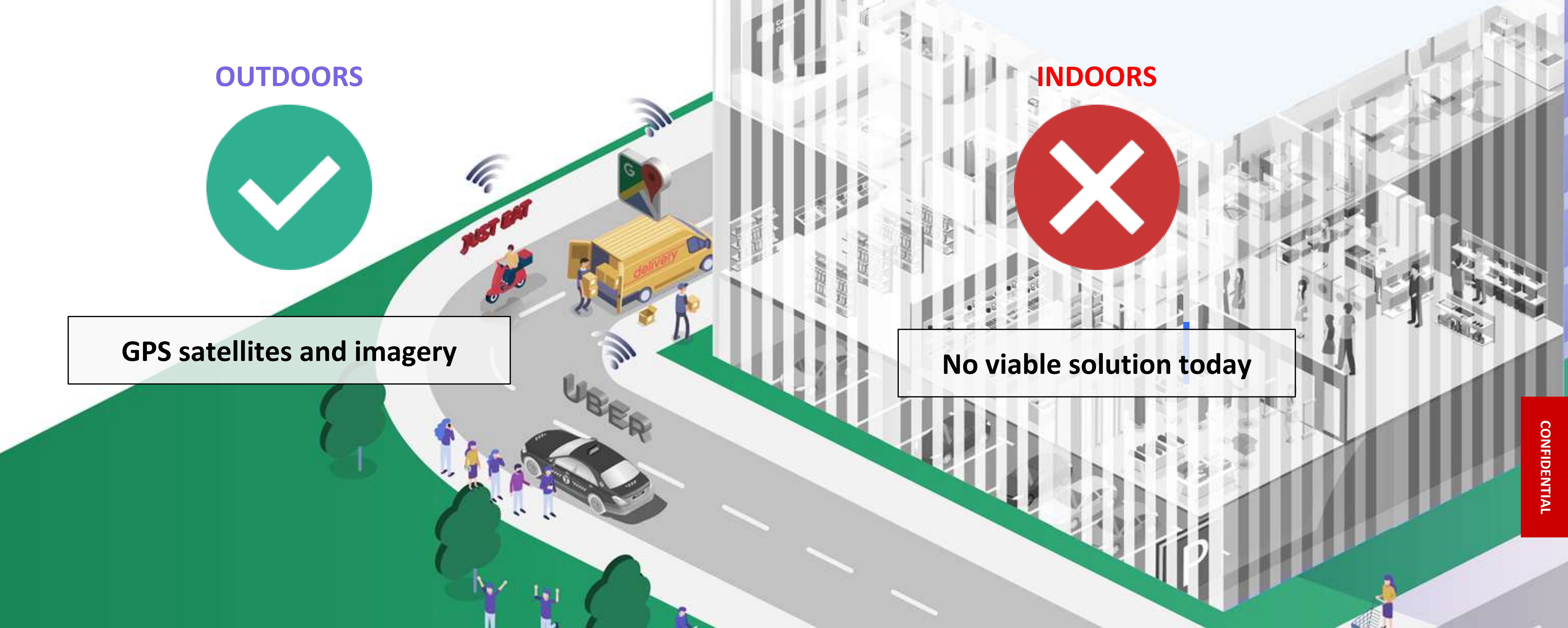
Indoor Location is crucial for Smart Buildings but there is no platform that **performs** and **scales**

OUTDOORS

GPS satellites and imagery

INDOORS

No viable solution today

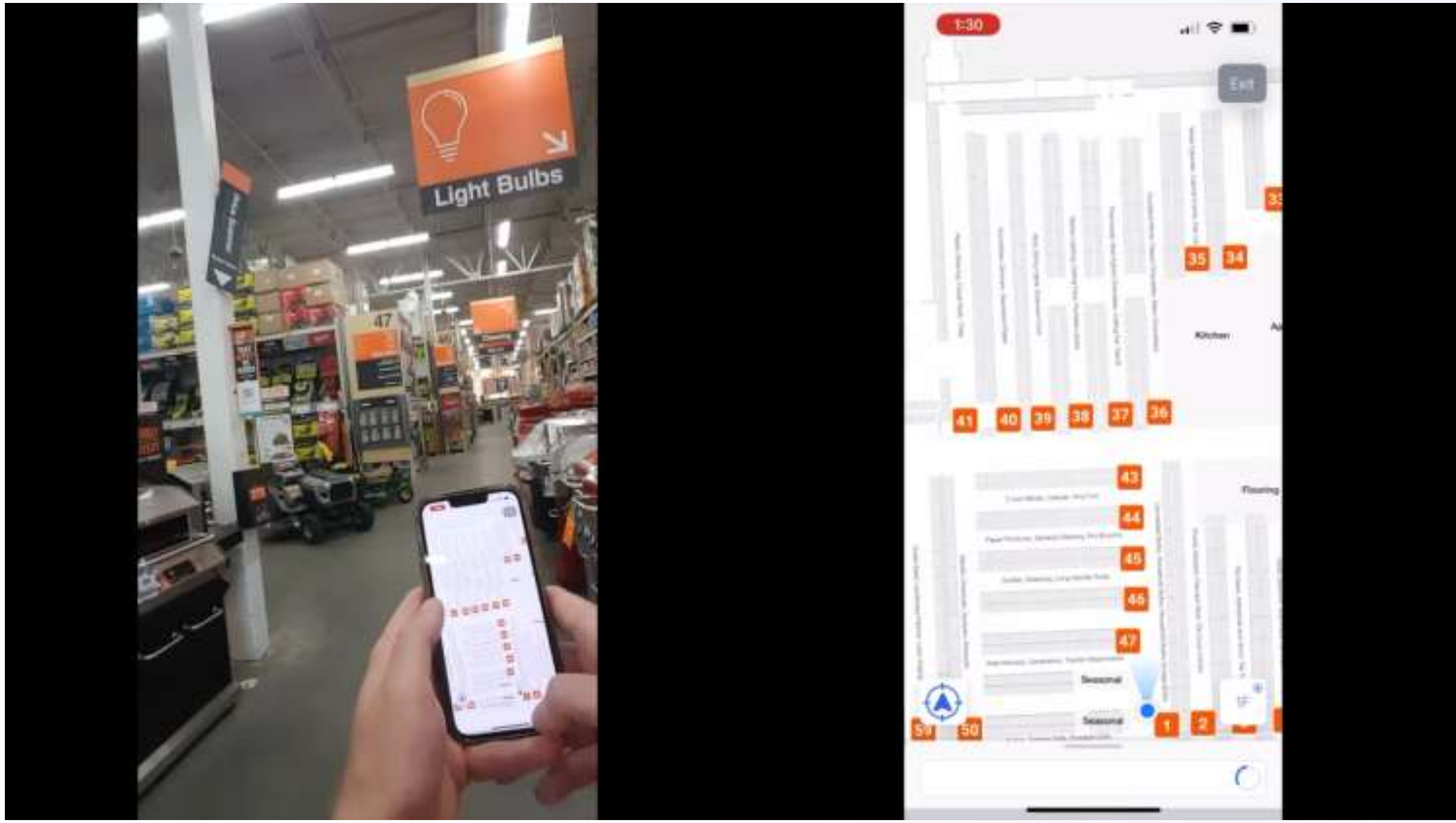


CONFIDENTIAL

Accurate and reliable Blue Dot powered by Pointr

Instant Location with Bluetooth

- ✅ **Instant Blue Dot**
- ✅ **1-3 m Accuracy**
- ✅ **Accurate Orientation** (no compass)
- ✅ **Ultra Scalable** (no fingerprinting)



Meet Pointr Maps™ Platform

Pointr is the inventor behind MapScale®, the first and only AI Mapping solution for scale.

Pointr Maps™ is an API-first platform offering:

Indoor Maps

AI Mapping

Analytics

Wayfinding

Geofencing

Indoor Location - Blue Dot

Meet Pointr

Top choice of Fortune 100, inventors of AI-based mapping

We're live in 5,000+ buildings and have digitized over 2 billion square feet.

We envision a world in which every building is smart — helping your teams find people, rooms, and resources — unlocking productivity and workplace efficiency.

Thank you!

Marianne Slamich
CMO
+447426321320
marianne.slamich@pointr.tech

‘Advances in Applied Muon Positioning’

Chris Steer
Managing Director
Geoptic
https://geoptic.co.uk

Advances in Applied Muon Positioning

Indoor Positioning: Where are we?

Dr Chris Steer
chris.steer@geoptic.co.uk

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Muon Imaging Systems

November 12th 2025

Structures and Subsurface Muon Monitoring

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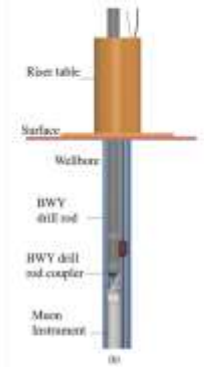
Instrument Form-Factors

Borehole Detectors

60mm by 220cm | 15kg (Air) | 5W | <2km water



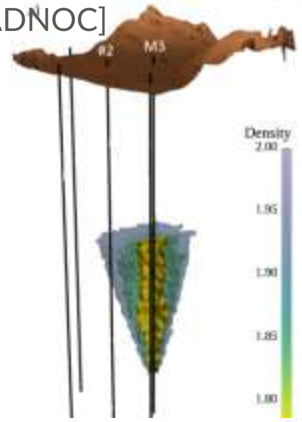
Compact High Resolution Detectors

39cm by 30cm by 17cm | 7kg | 5W

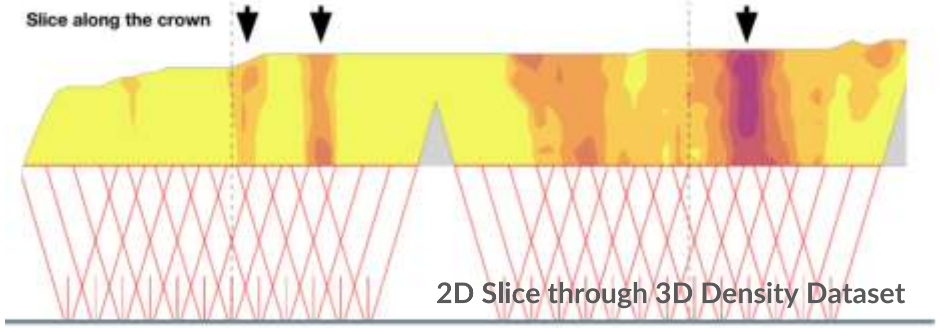
… plus others and bespoke

Example Applications

Density Image of Subsurface Stored CO2
[Geoptic, SINTEF and ADNOC]

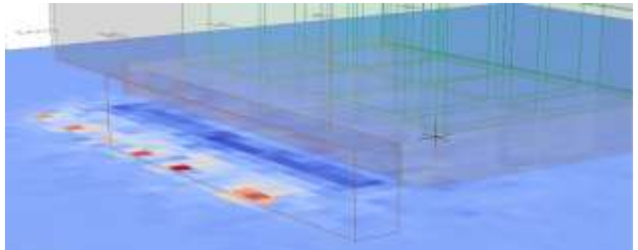


Canal Tunnel Overburden Survey
[Geoptic, CRT and Arcadis]

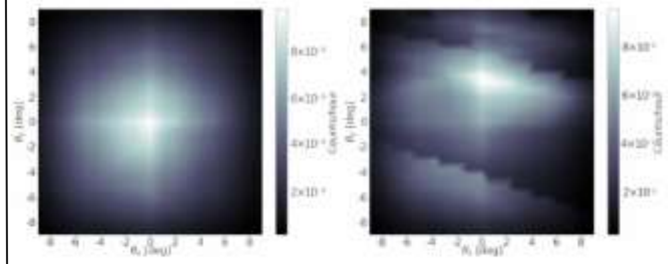


Railway Tunnel Detection of Voids and Concealed Subsurface Shafts
[Geoptic, Network Rail and RSK]

Advanced Calculations for New Applications and Structures



Digital Twin Feasibility Simulations of leakage detection underneath building [Geoptic and NNL]



Feasibility Calculations of Muon Fault Detection
[Geoptic, IAEA, NAGRA and BGE]

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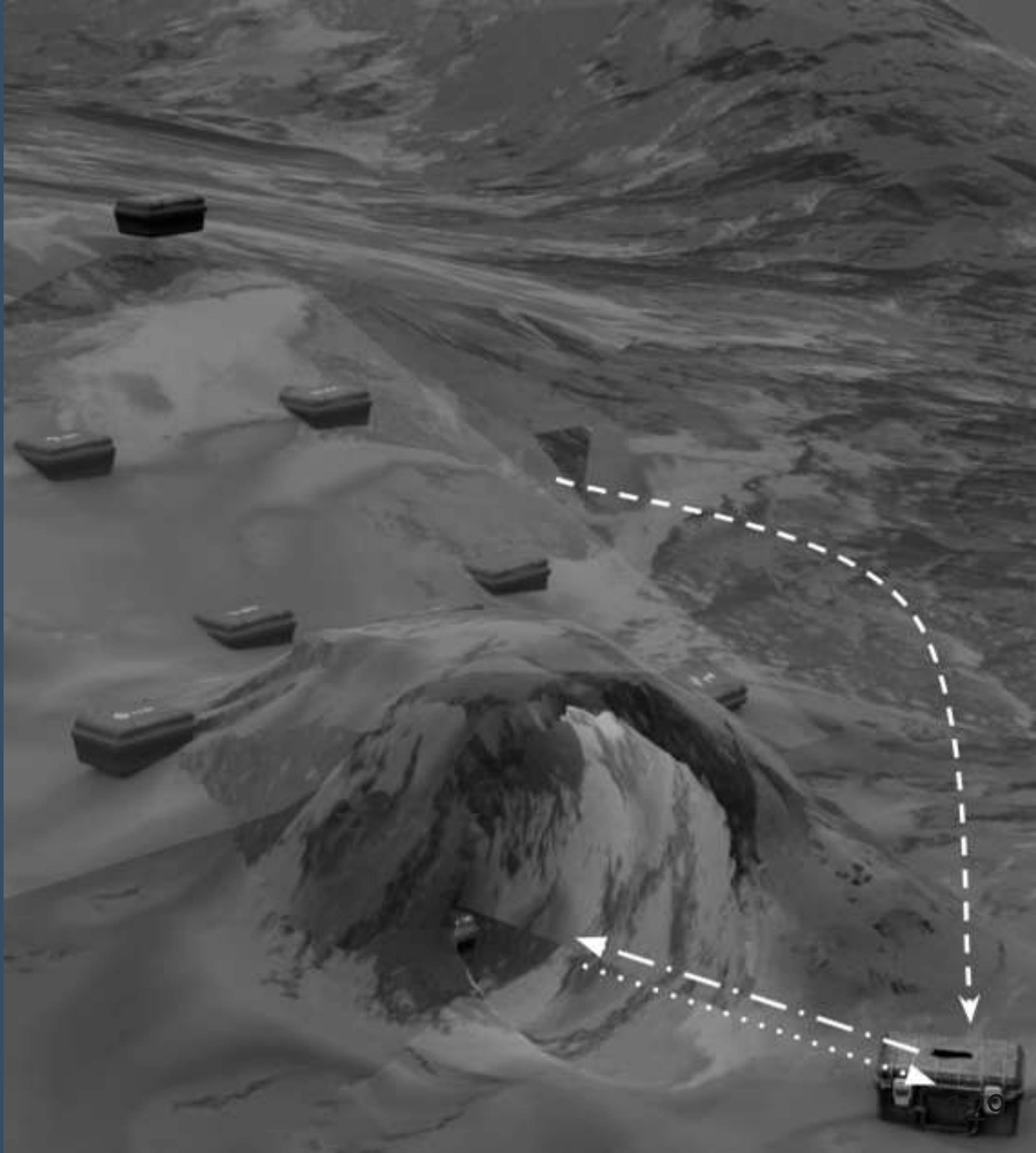
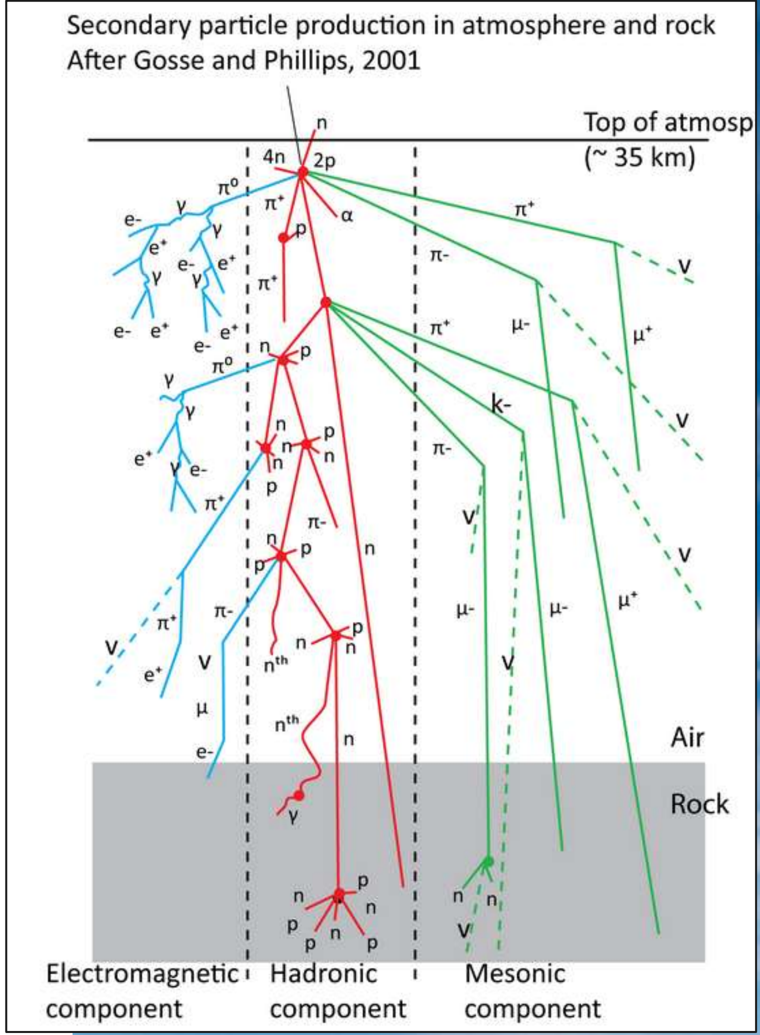
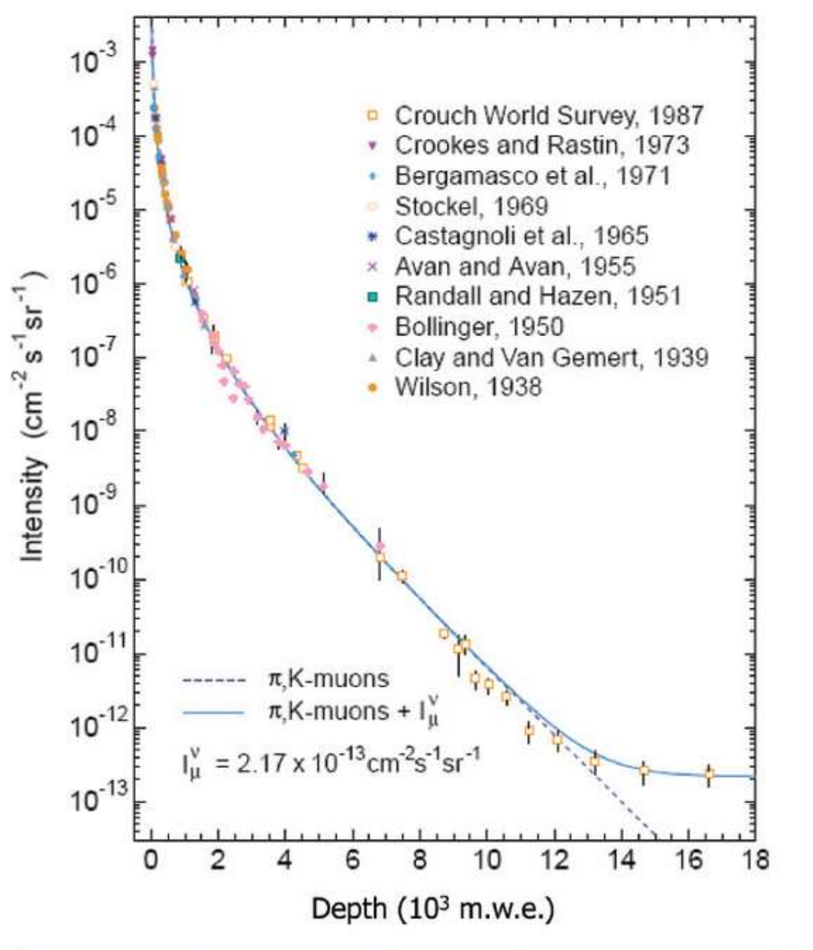
Introduction to Muon Positioning



What are Cosmic Ray Muons?

- High-energy particles are incident on the upper atmosphere
- The secondary cosmic ray flux at sea level is dominated by muons
  - 10,000 muons/minute/m²
  - Relativistic and high-energy
- Highly penetrating





Depth [mwe] = density [g/cm3] x thickness [m]

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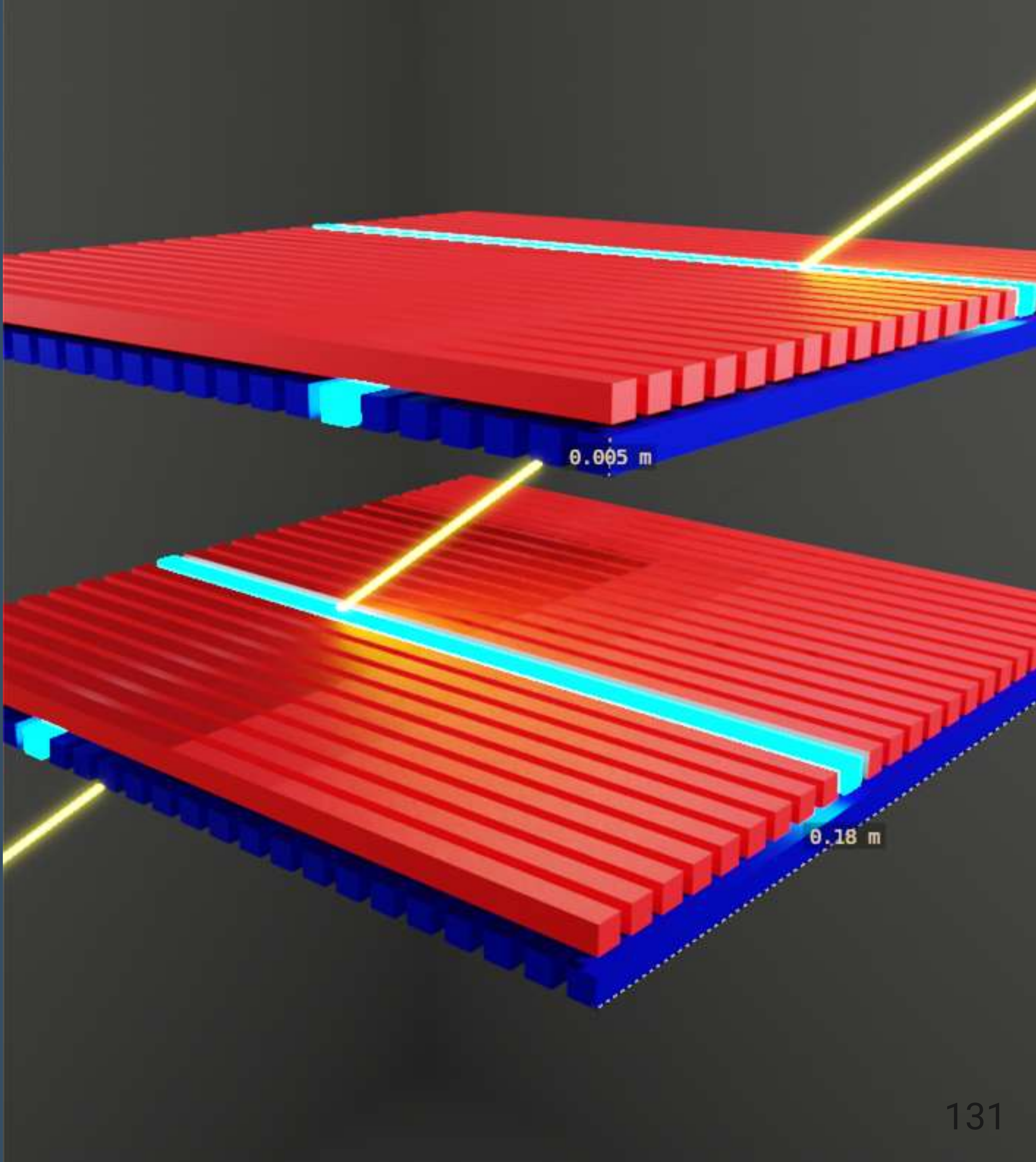
Muon Detection

- **Segmented Bar Arrangement**
- Material produces flash of photons
- Sensitive Photodetector
- Current pulse (typ. 10ns width)

Inferred Muon Event Information

- Hit time
- Hit location on detector
- Track direction



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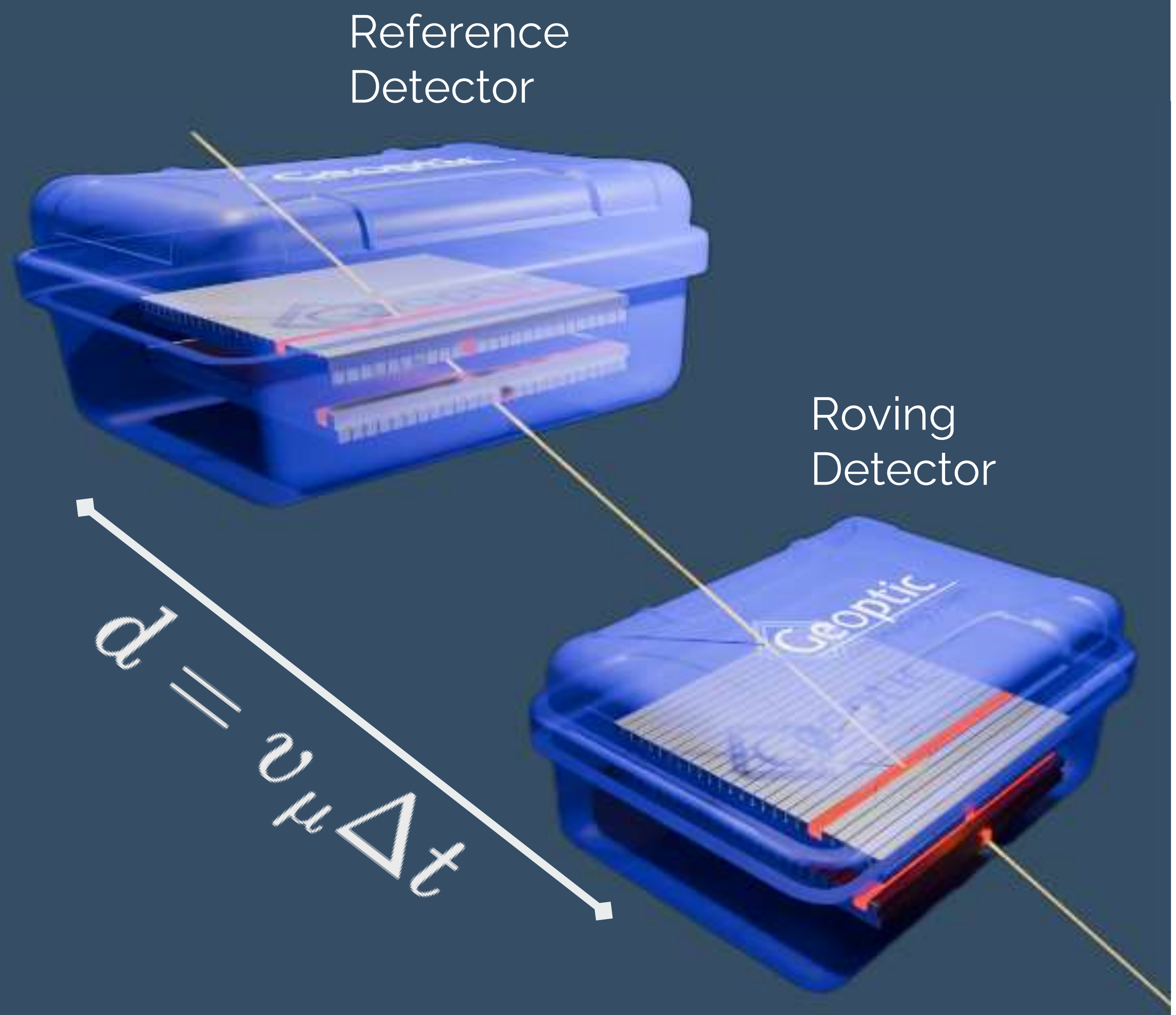
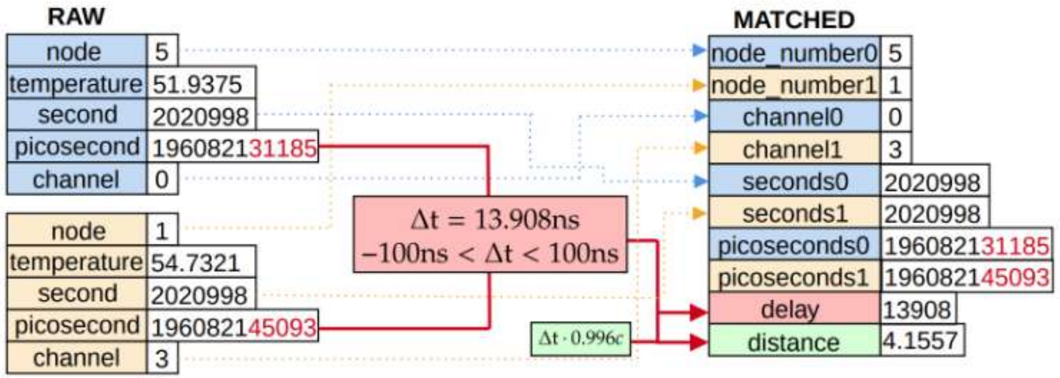
Timing-based Muon Positioning



- Single muon is coincident on one detector with a known position (reference) and one without (roving)
- Timing difference of hits can be converted to distance
- Standard multilateration with multiple reference detectors and a single roving detector
- Unsegmented detectors



Timing-based Positioning Implementation

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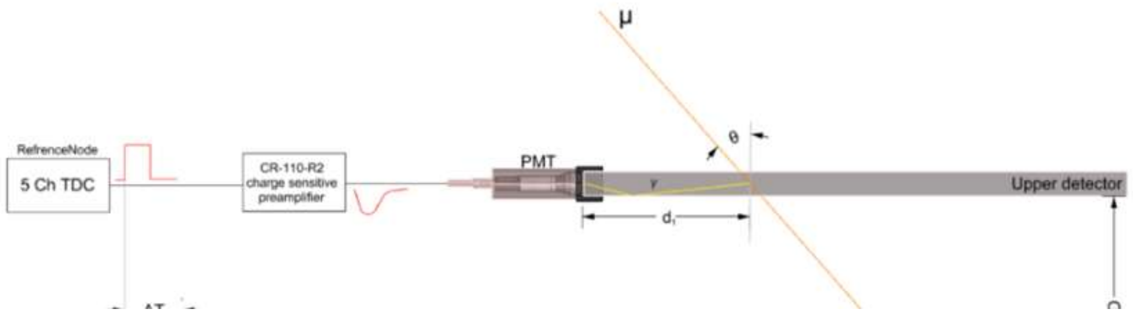
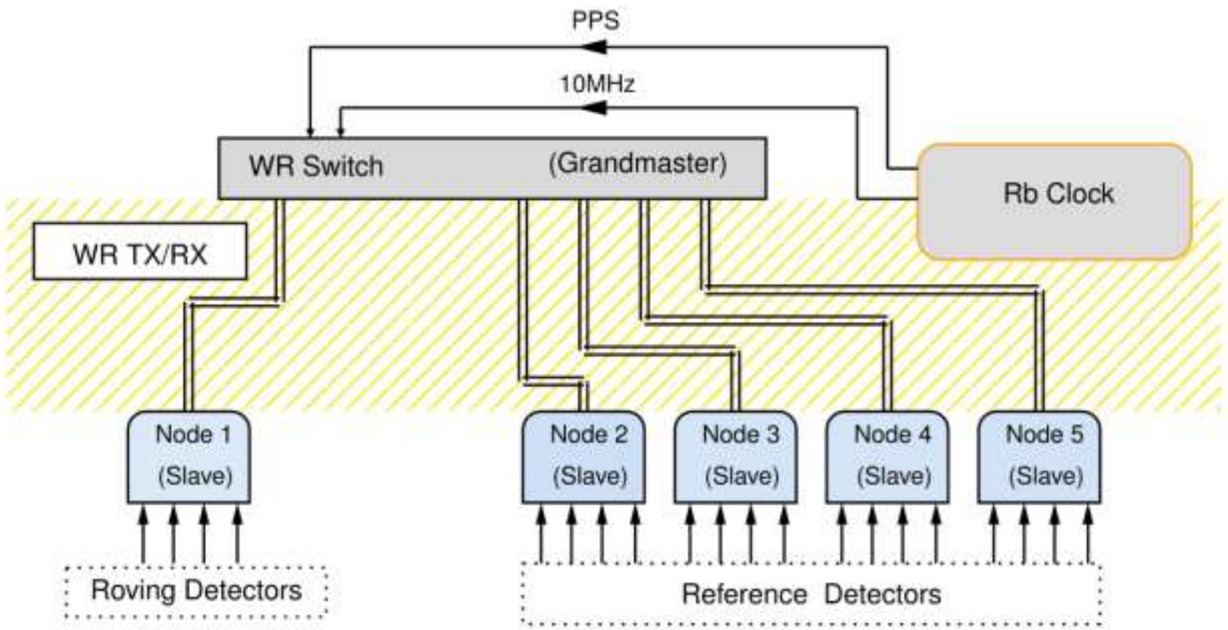


- Reference detector array shown at Pysählmi Mine, Finland
- Each node comprises four 15cm by 80cm detectors
- Readout is via time-to-digital converter
- Each node clock disciplined by White Rabbit timing distribution



Dense Urban, Underwater and Underground (‘22-’24)

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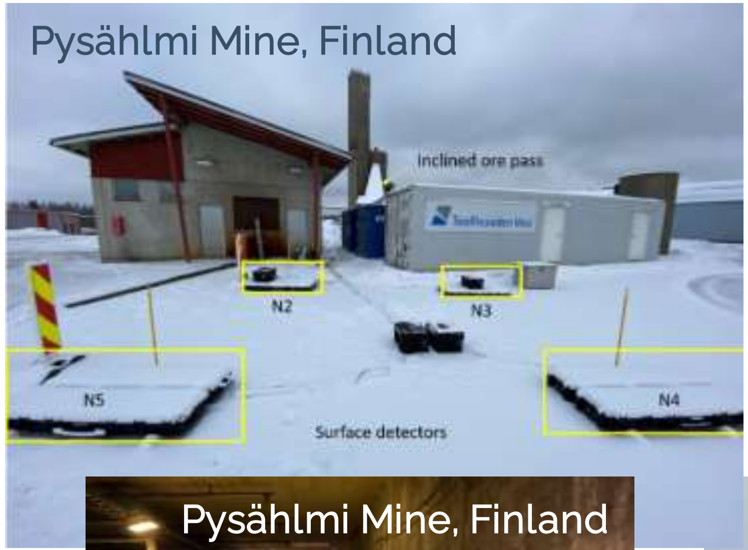
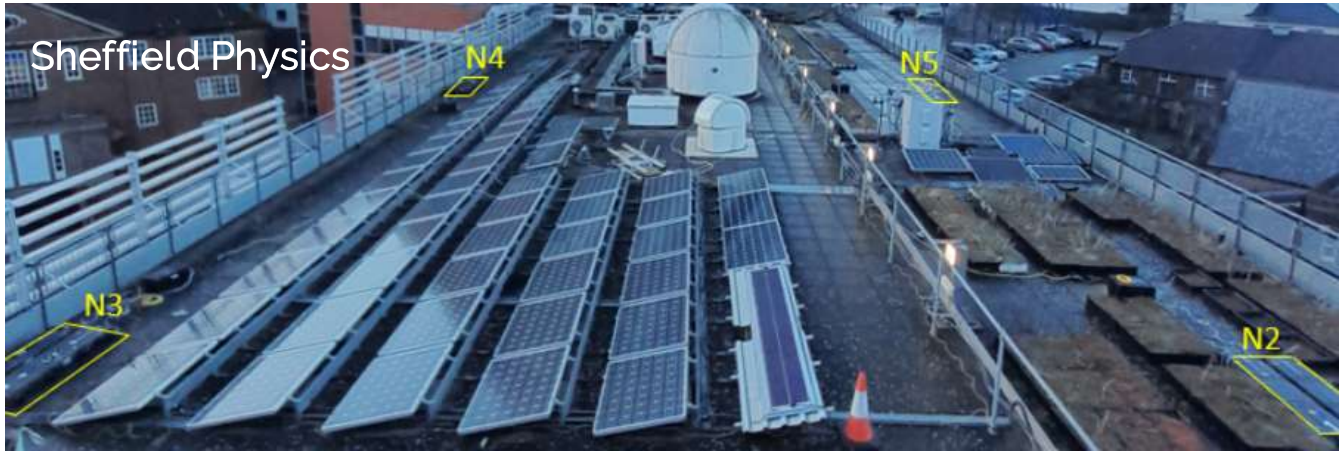
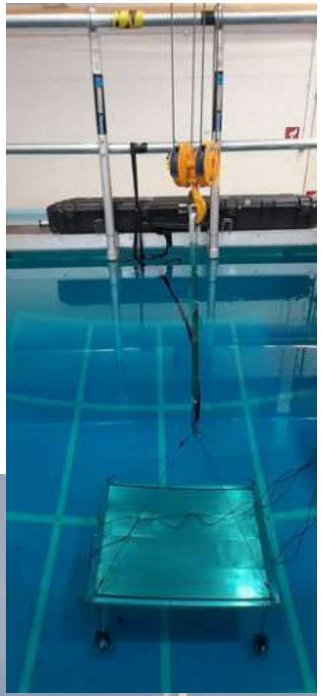
Pysählmi Mine, Finland



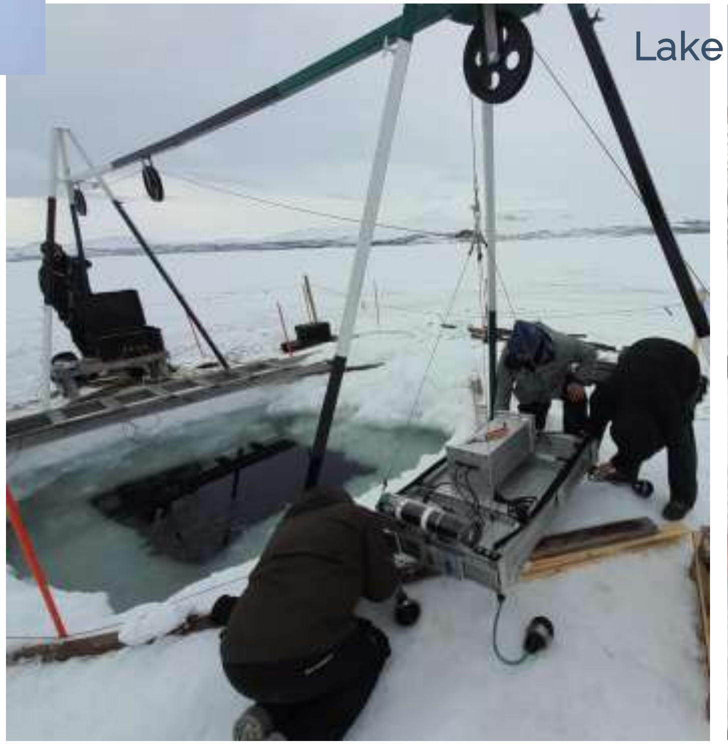
Sheffield Physics

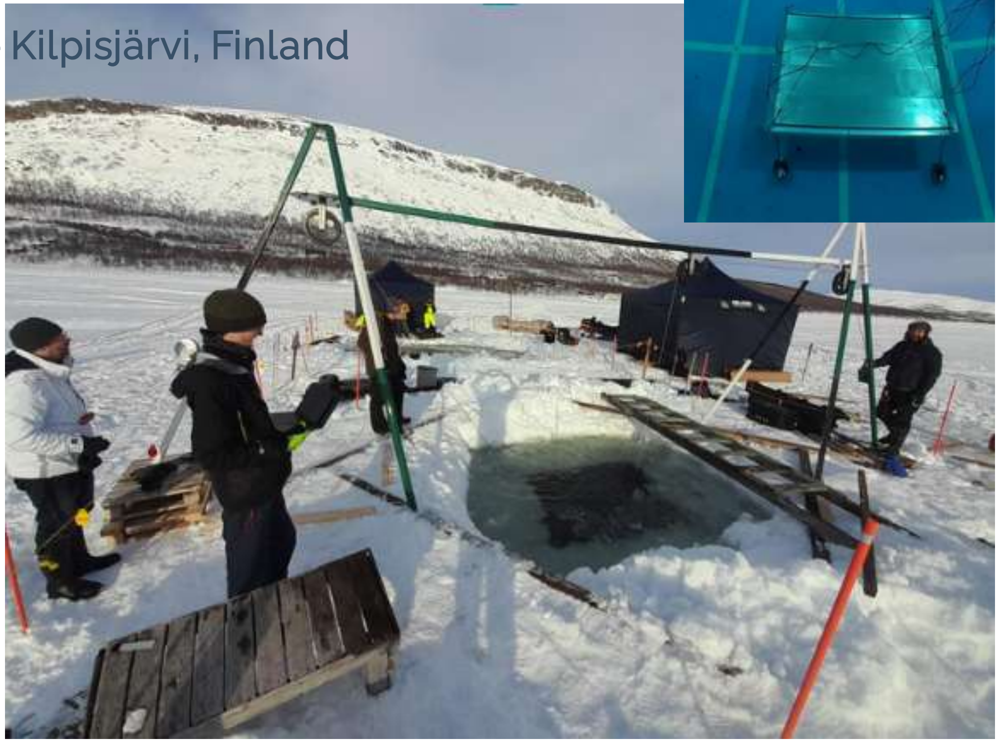




Pysählmi Mine, Finland

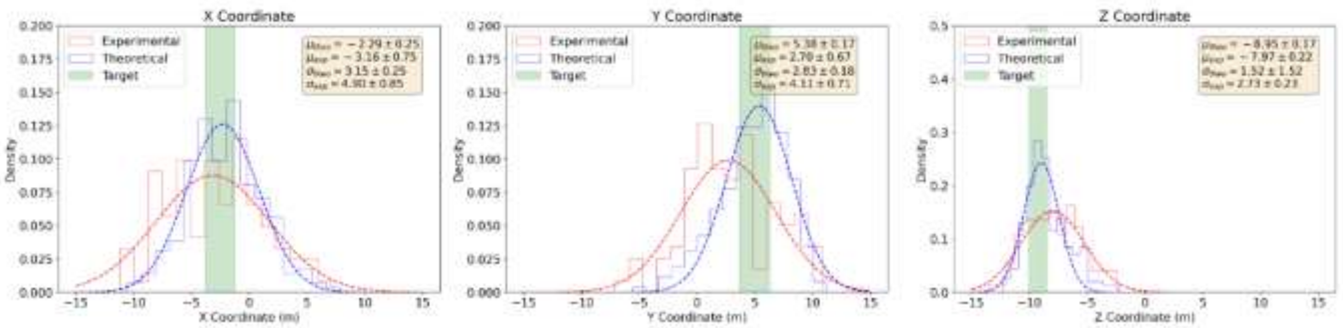
Lake Kilpisjärvi, Finland





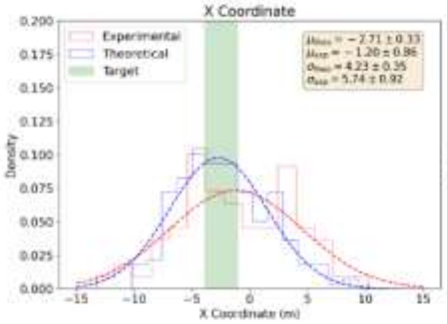
Results Summary

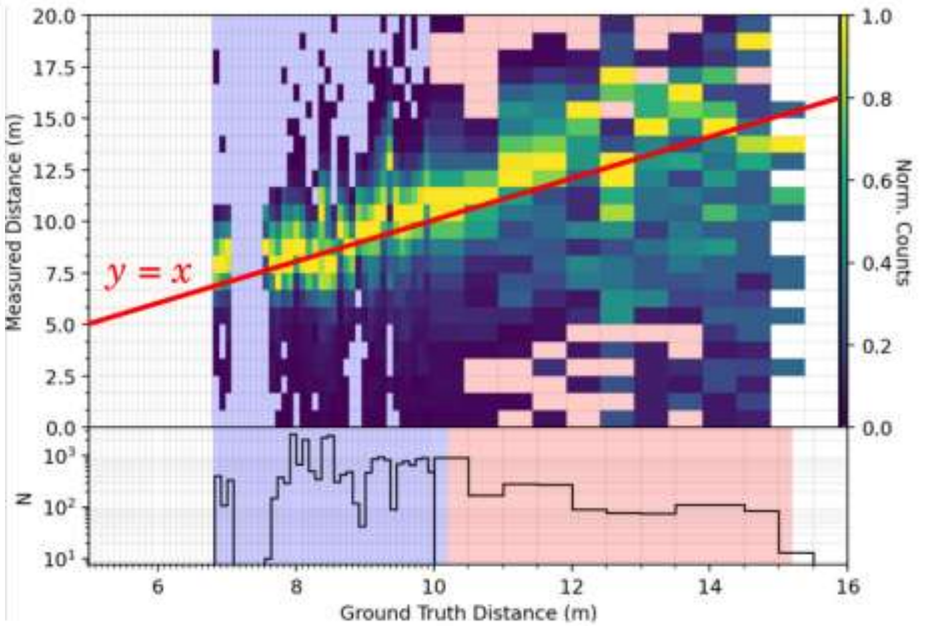
- Range up to 30m slant distance, 20m vertical
- Broad, good agreement with particle transport simulations and studies
- **Position Error:** In the region of 2m (typ.)
- **Time-to-position:** ~ 20 minutes



(c) Position 4

- Spreads correspond to instrumental timing issues:
- 7ns from PMT jitter
- <3ns from photon transport





- Roving clock drift limits total deployed operational time
- Competes against minimum four-fold reference-roving detector
- Depth/Distance limited by instrument accidental coincidences

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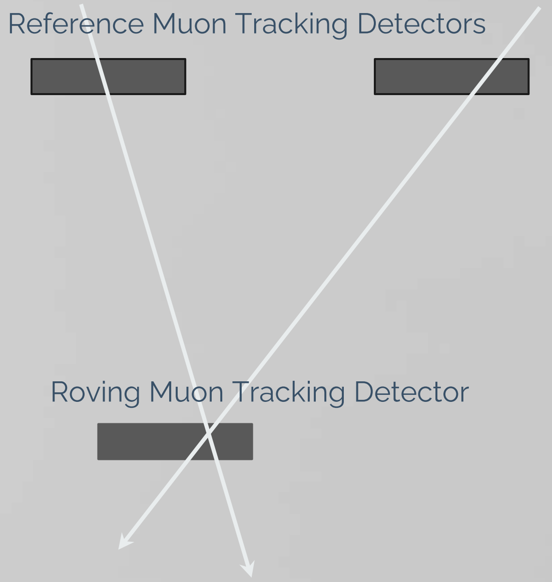
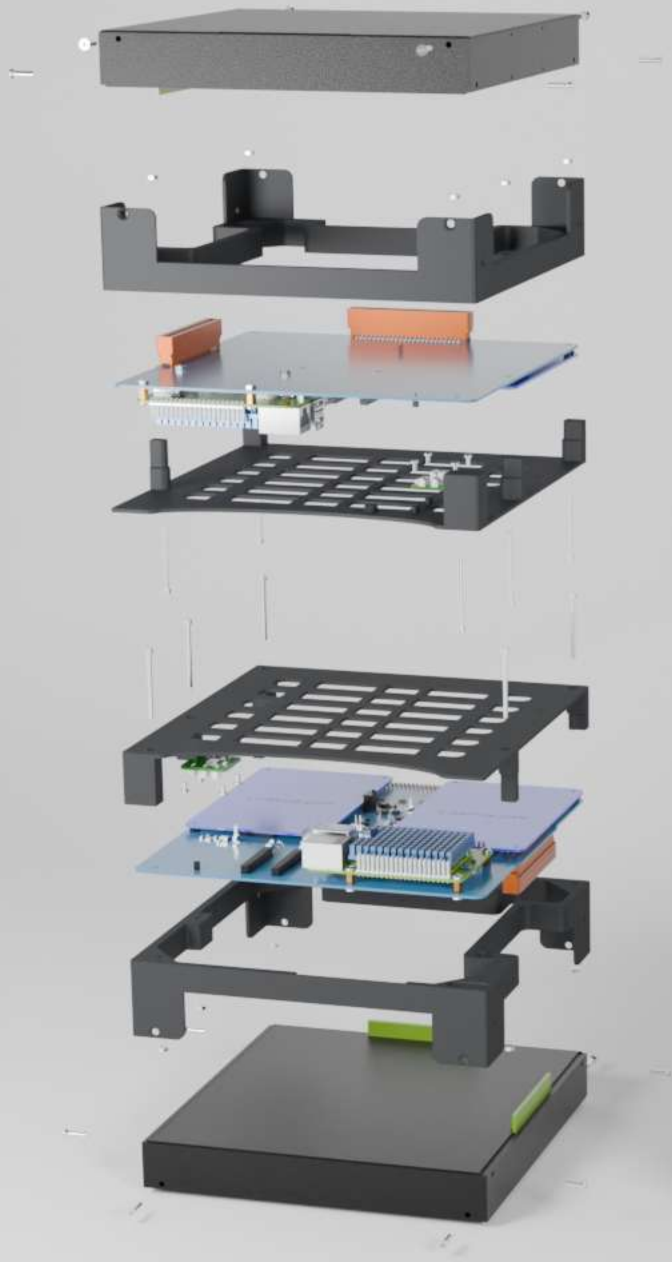
Trajectory-based Muon Positioning

- Re-designed detector node
- Improved track angular resolution
- Lower accidentals likelihood
- Reference and roving detectors measure direction of co-incident event
- Event vectors from reference detectors to roving detector system
- **Position** estimated as region-of-closest approach of vector pairs
- Min. two events for position estimate





Redesigned Muon Tracking Detector

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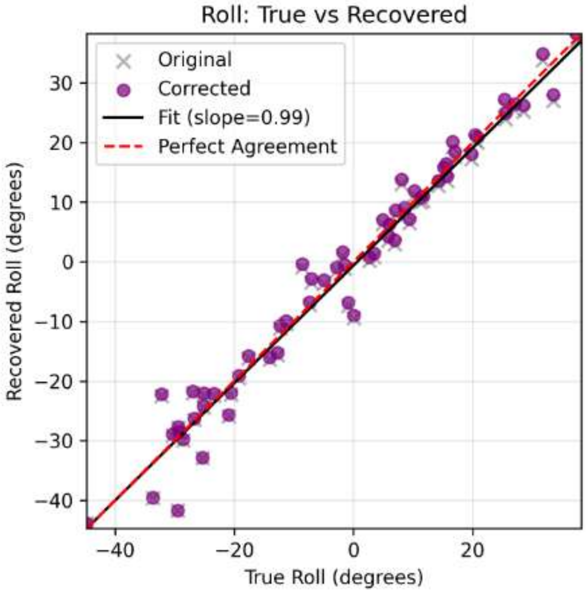
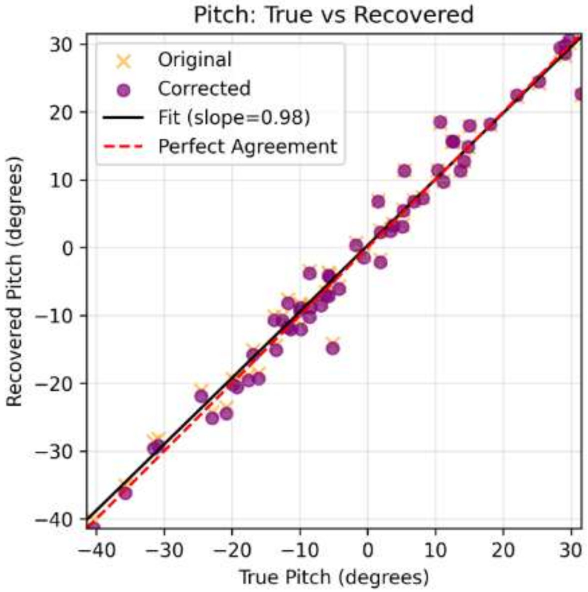
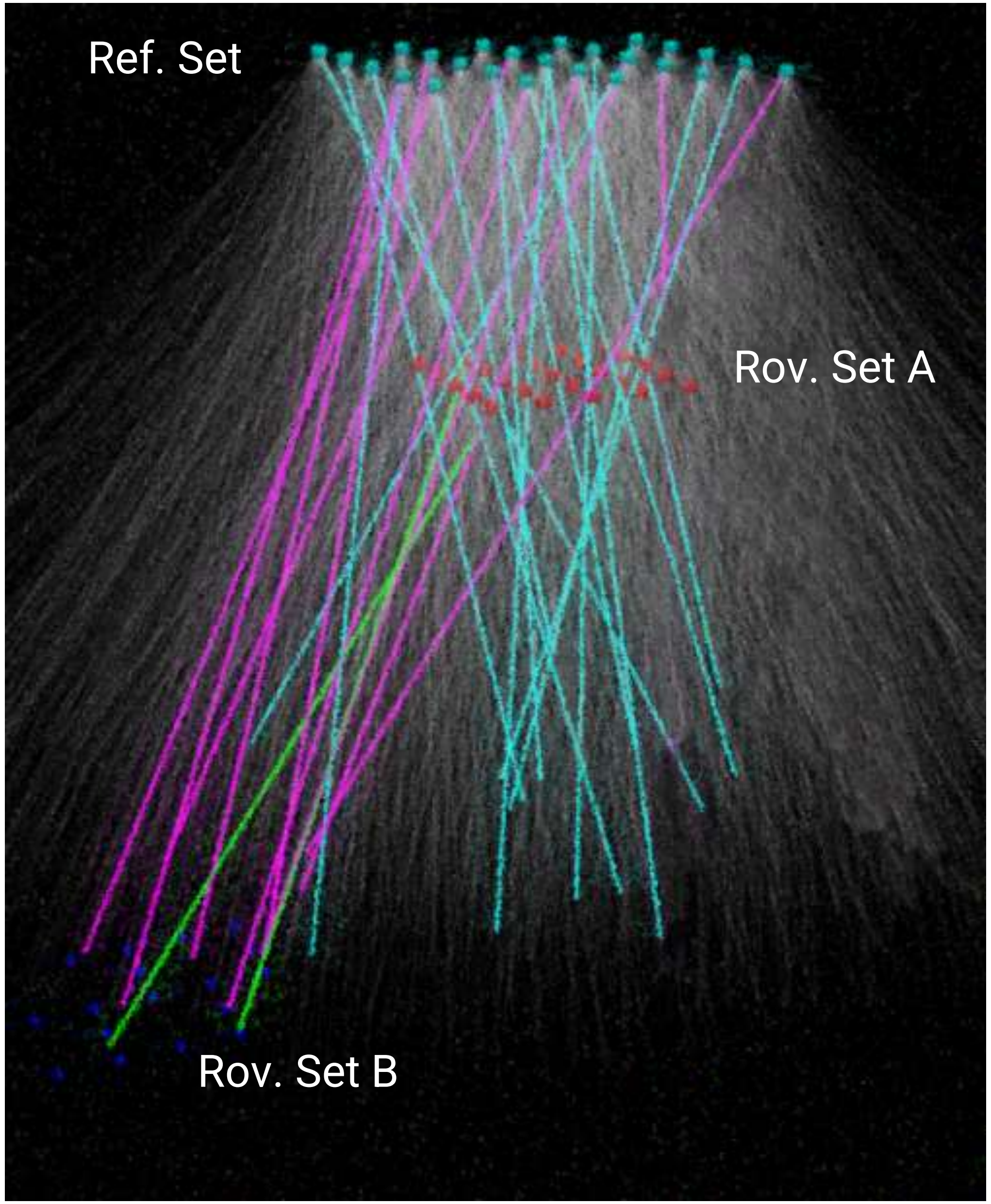
- Development focused on algorithm development in three areas

- Robust **position estimation** based on event paired vectors
- Detector system **orientation estimation** from muon information alone
- **Position inference transfer** from one roving detector to another

$$\mathbf{q}* = \arg\min_{q} \sum_{i=1}^{N} \min_{t_i} \left\| \mathbf{q} - \left(\mathbf{p}_i + t_i \hat{\mathbf{d}}_i \right) \right\|$$





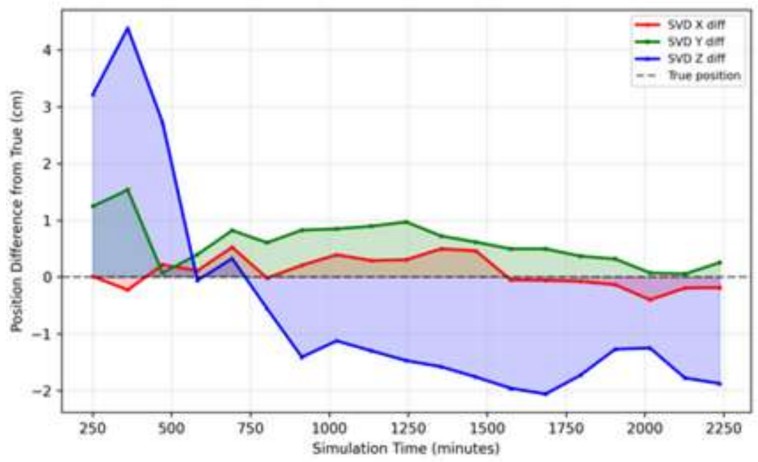


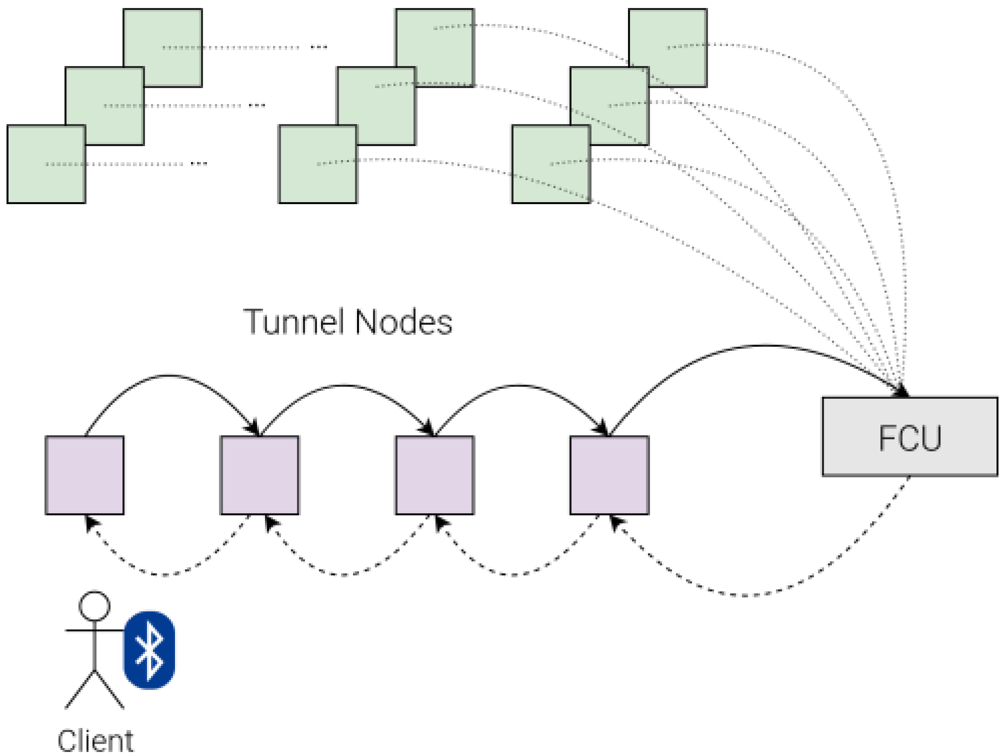
Interim Results

- Initial trajectory based *simulated* results suggest improved performance and fit
- **Time-to-estimate:** 5 mins - 2 hours at 10-20m

  - Scales with detector surface area
- **Position Error:** <5cm (known orientation) <50cm (without)

- Easier to deploy
  - Lighter, lower power consumption
  - Short setup time to muon tracking
  - Position and orientation inference





Conclusions and Near-term Developments

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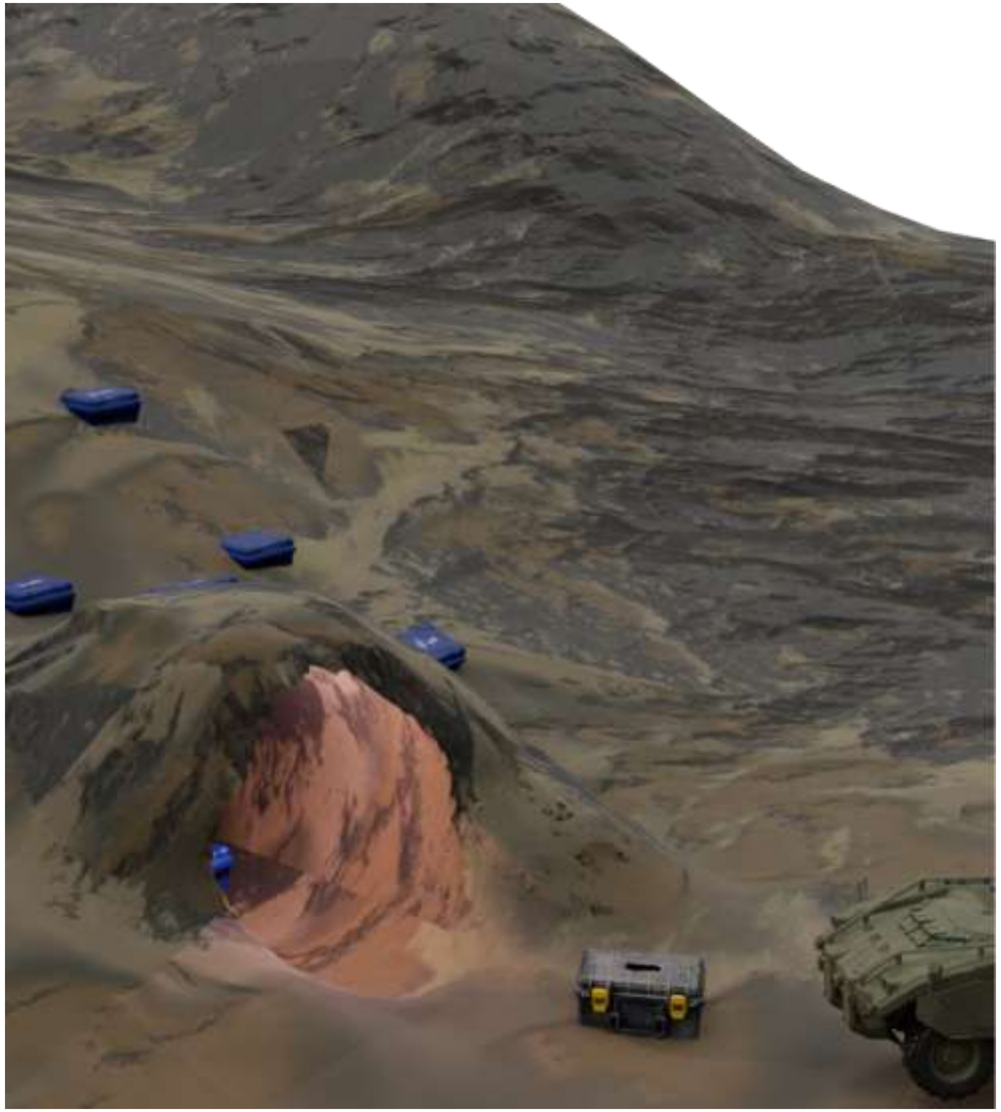
- Geoptic has implemented a muon positioning based on time and working to develop a trajectory based system
- Building test network of 10 detector tracking units for subsurface imaging and waypoint position network
- Technical implementation of:
  - Implementation of LORA (from WiFi)
  - Field-compute unit build to coordinate messaging and
  - Last hop BLE to user
  - Weight reduction considerations
- Initial tunnel network testing after October 2026



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Thank you

Contact:

Dr Chris Steer

E-mail: chris.steer@geoptic.co.uk

Telephone: +44 1256 541616

Office: Geoptic, Beechcroft Barn, Pickaxe Lane, South Warnborough, Hampshire RG29 1SD, United Kingdom.

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Tanaka, Hiroyuki KM. *Scientific Reports* 13.1 (2023): 15272.
Tanaka, Hiroyuki KM. *Scientific Reports* 10.1 (2020): 18896.

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