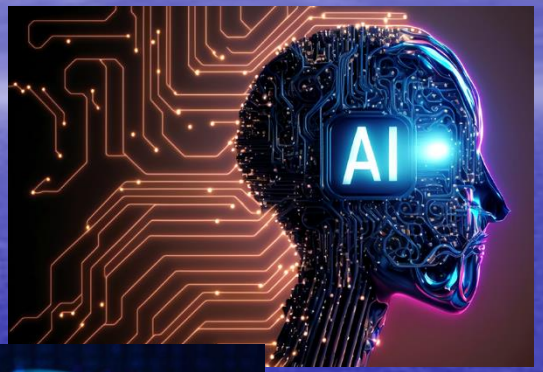
Resilient Ubiquitous Positioning: Prospective and Challenges

Wu Chen
Department of Land Surveying and Geoinformatics (LSGI),
The Hong Kong Polytechnic University

Where and When?

Positioning, Navigation, Timing (PNT): Key Technology to support human mobility

PNT infrastructure is crucial for AI/Digital Economy



Positioning Methods

- Land Marking
- Celestial Positioning
- Intersection

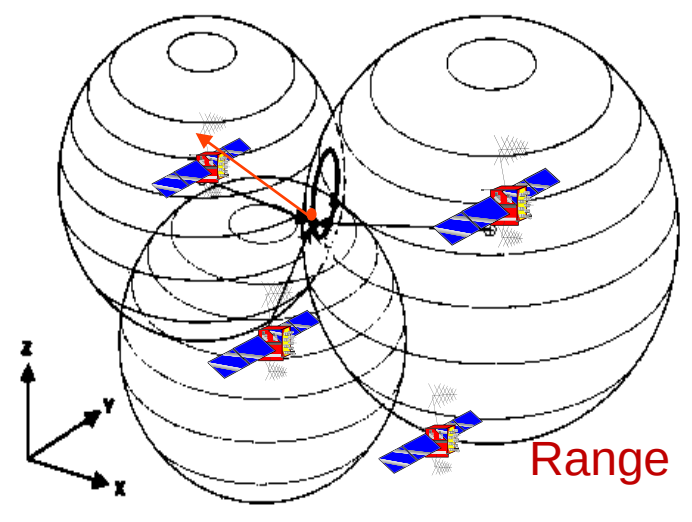
Land Marking

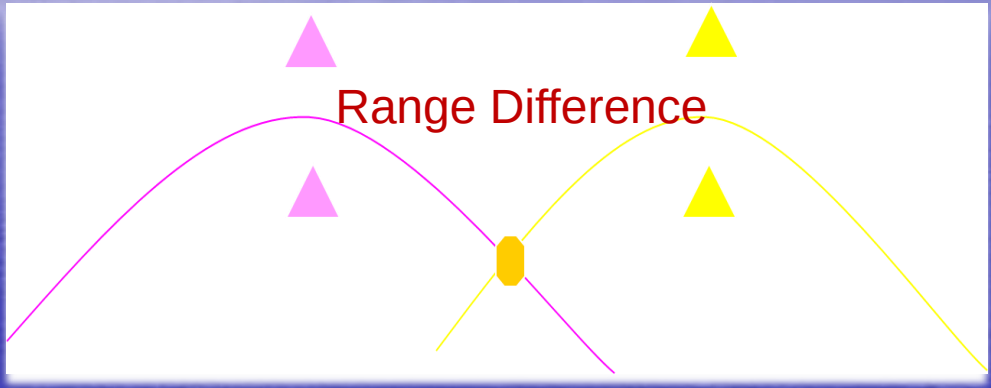
- Visual
  - Nature land shapes
  - Buildings
  - Images
  - Lighthouse, “obo”
- Non-visual
  - Beacons
  - Terrain Matching
  - Signal Matching (“Finger print”)

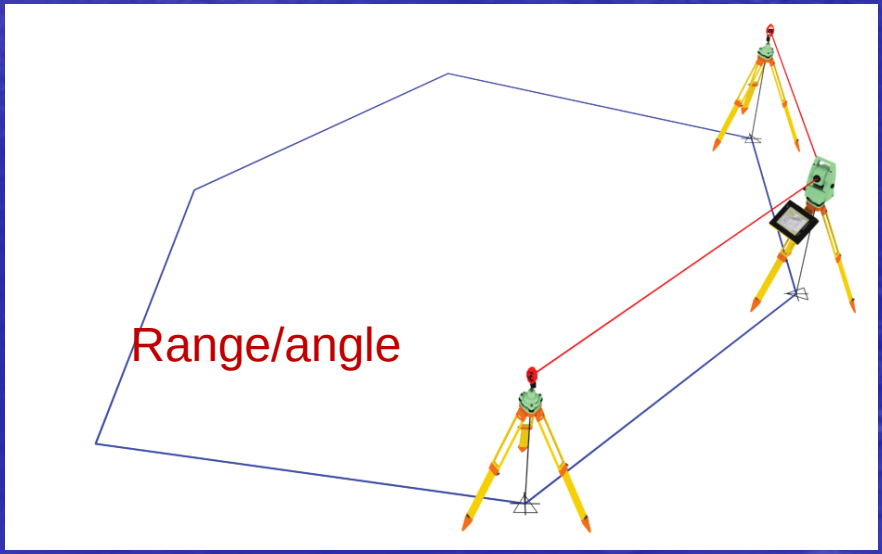
Celestial Positioning

- Reference to Stars
- Direction
  - "Star of North"
- Latitude
  - Angle of star location
- Longitude
  - Time when stars passing

Intersection: distance and angle

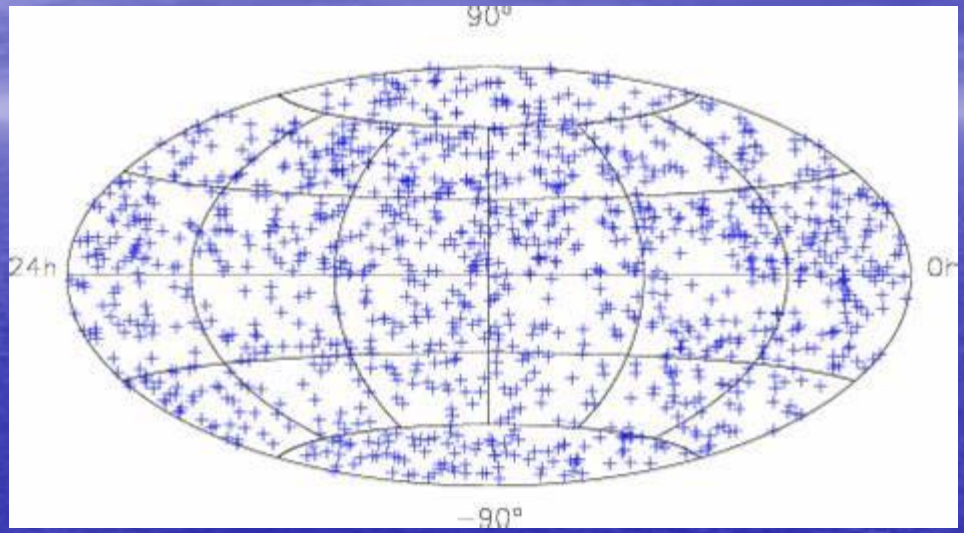


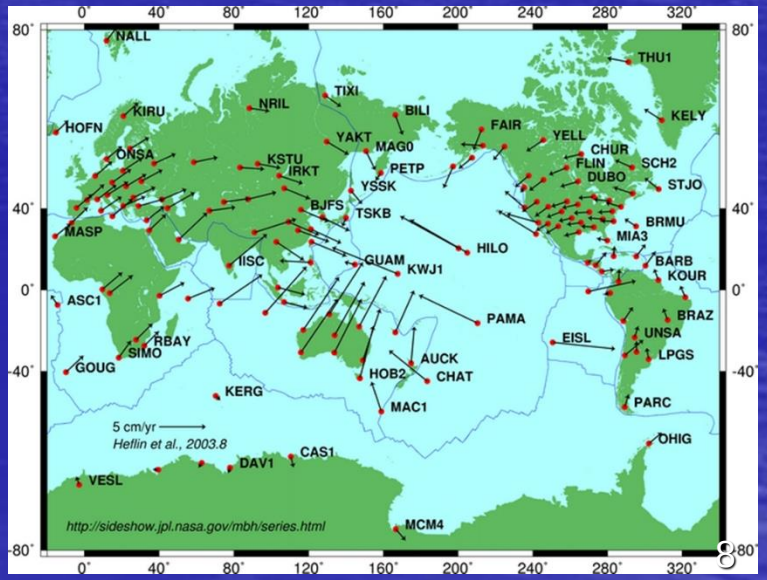




Need to establish a reference frame

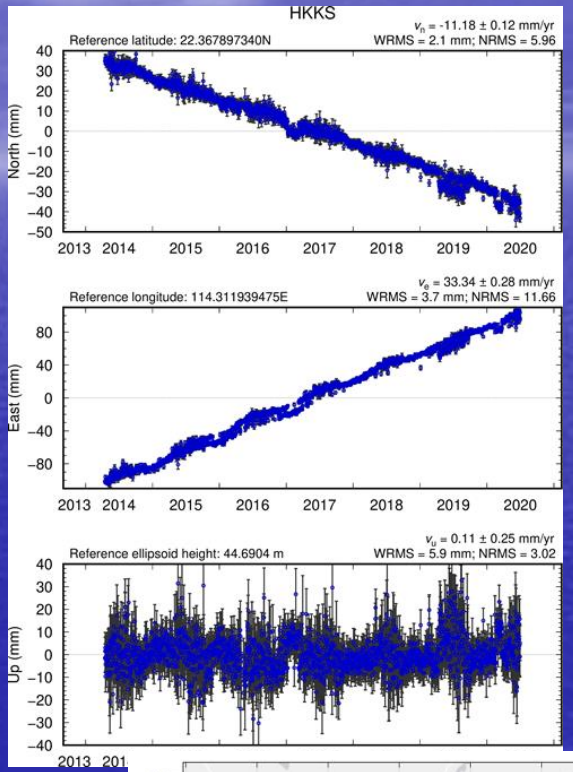
- All the measurements are relative
- Need to related to a reference frame
- Need to consider site movement

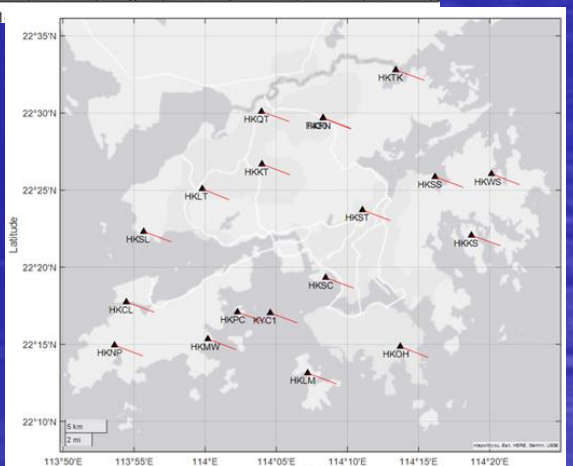




Local Realization of Global Reference Frame

- Internationally: ITRF
- Link to ITRF through local GNSS Ref Stn
- Estimate stn velocity
- Align to the epoch defined
  - i.e. Hong Kong: ITRF96/98
- Different with current GNSS: >70 cm

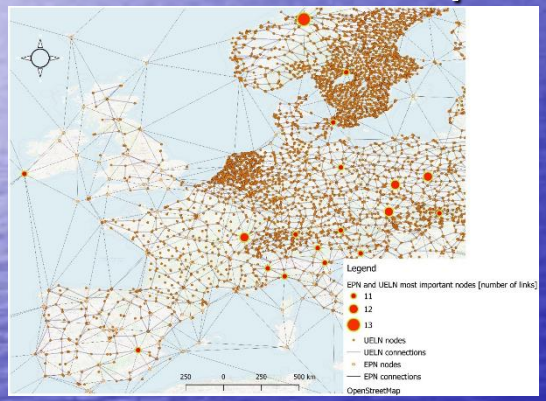




Historically, how can we find where we are?

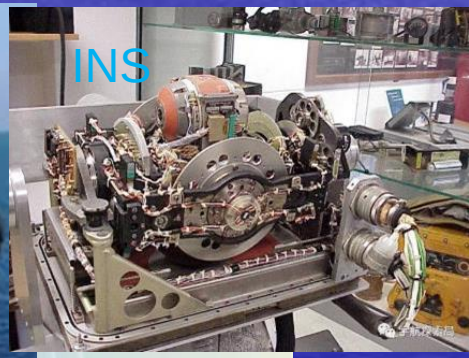
Normal People

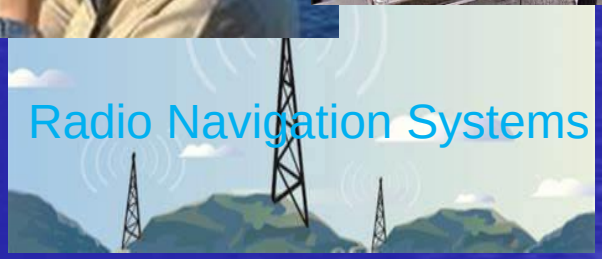
- Reference to Maps



Navigator

- Real-time coordinates

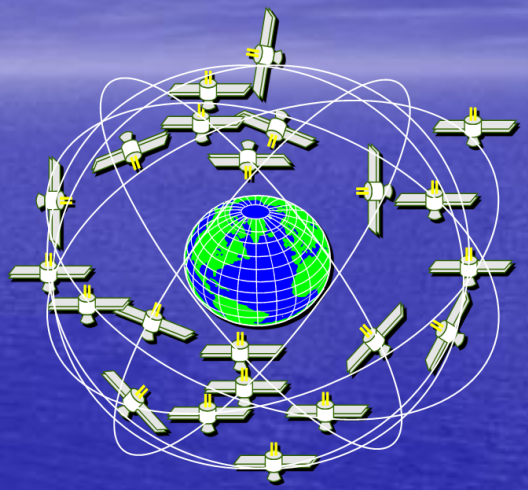




Special Skill and Very Costly

GNSS: Revolutionized PNT

- Global Reference Frame, through satellites
- PNT services: anywhere and anytime
- High accuracy: cm-m level
- Link map to coordinates
- Low cost
- Anyone can use
- However, GNSS does not work indoor



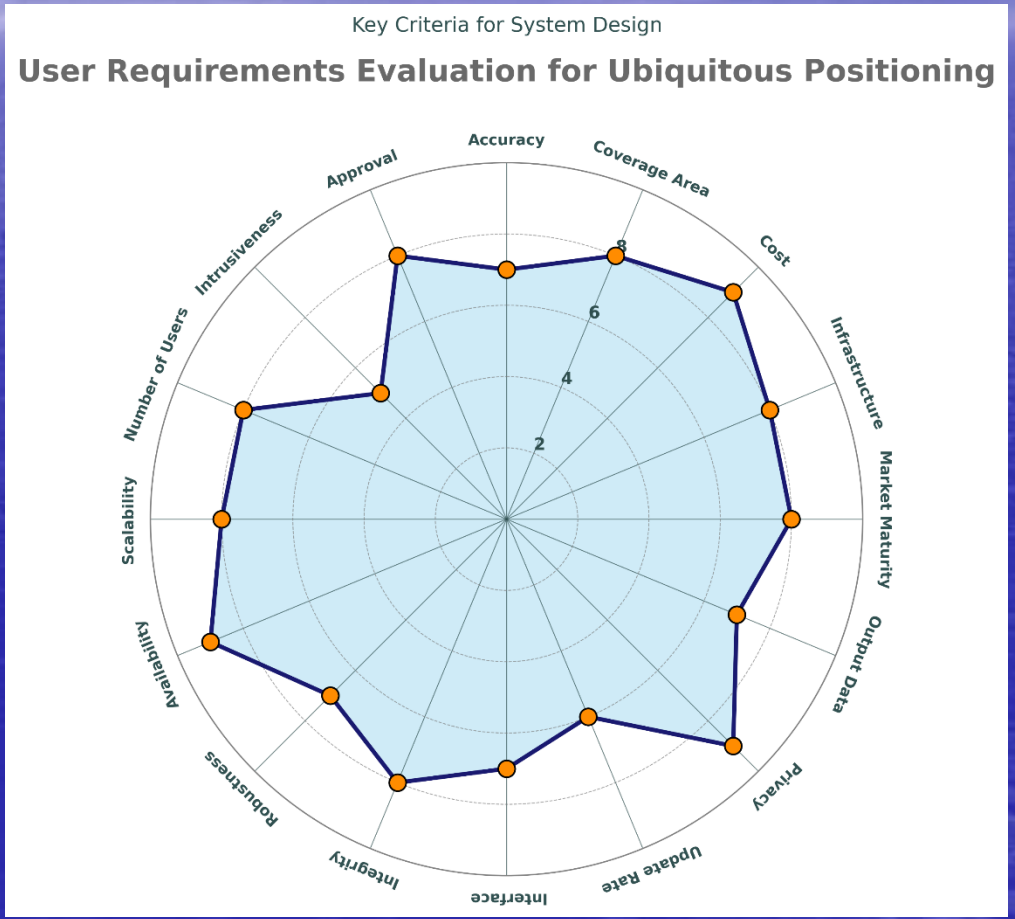
Definition

– Ubiquitous p
refers to de
user's locati
continuous
seamlessly
various en
including inc
outdoor spa
significance
to provide r
continuous,
aware locati
that benefits
and service

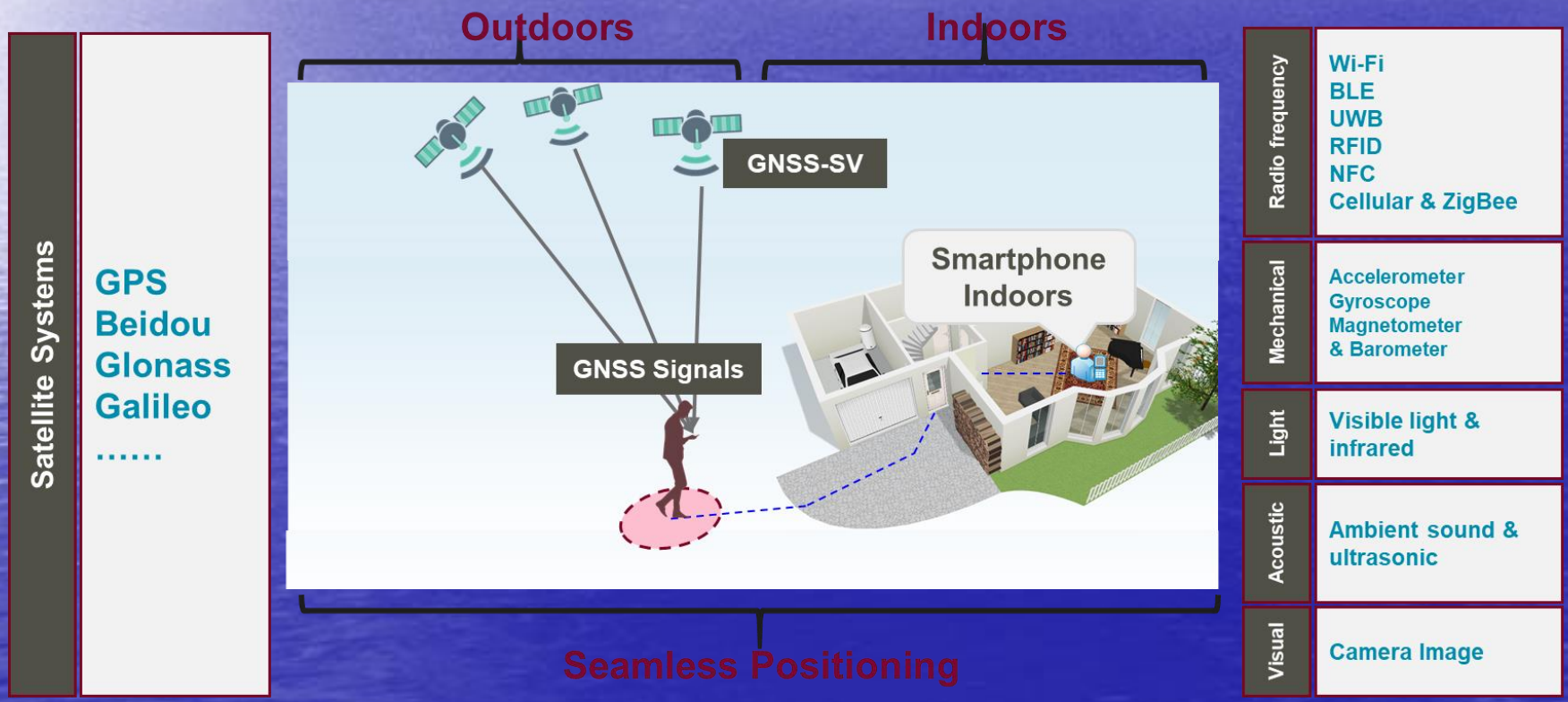
Some Examples of Ubiquitous Positioning

PNT Requirements

- Accuracy
  - How good is the position?
- Integrity
  - How safe is it?
- Resilience
  - What if there is a failure?
- Cost
  - Can I afford it?

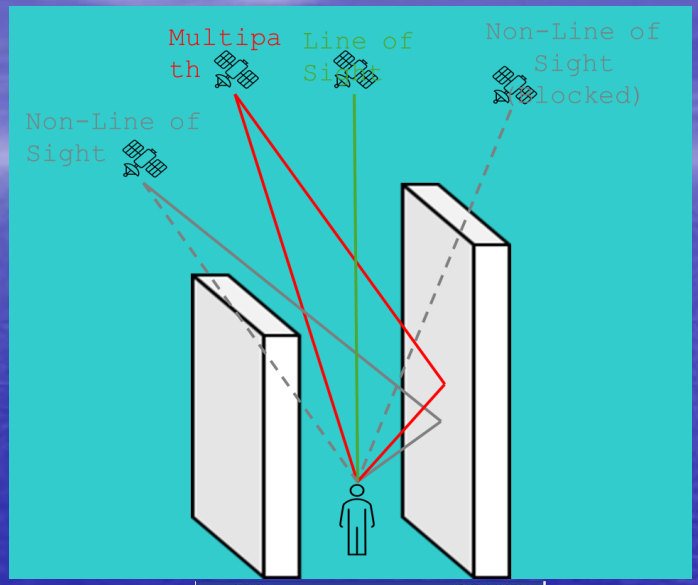


Current Solution



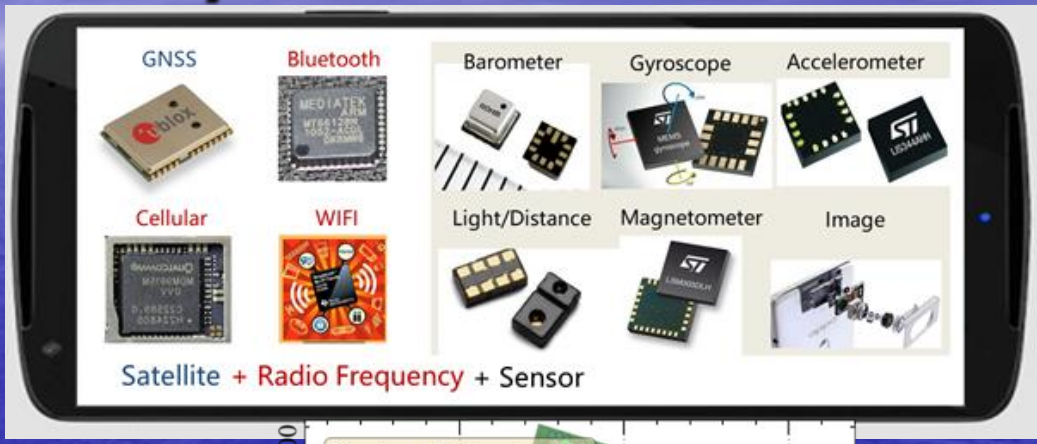
GNSS positioning in urban environments

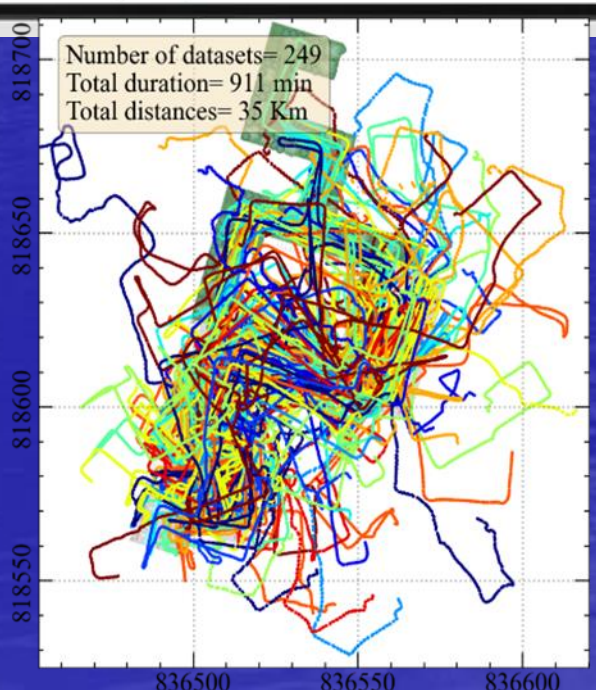
- Signal Blockage
  - Less satellites observed
- Multipath/NLOS
  - Measurement error increase
- Positioning Error
  - Can reach 100 m
- RTK
  - Very difficult



Ubiquitous Positioning: integration of many sensors

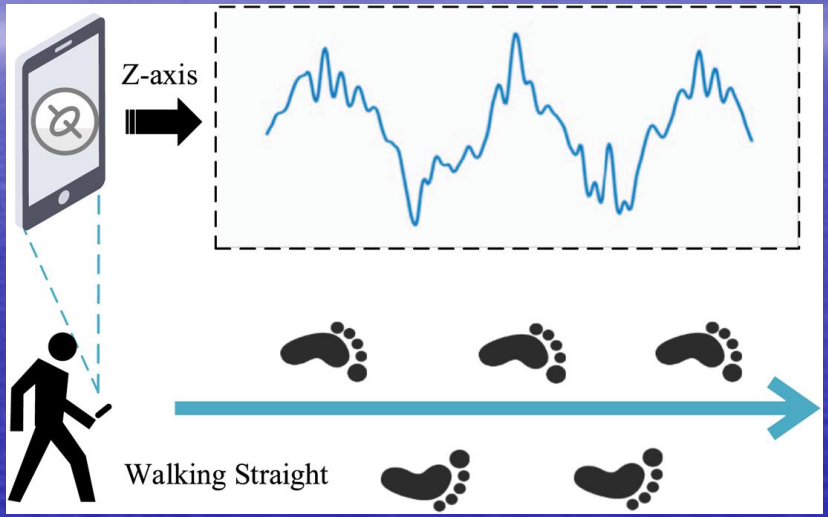
- Smart phone can provide continuous positioning indoor
  - IMU
  - WiFi, Bluetooth, UWB
  - Magnetometer, barometer
  - Camera
- But accuracy is low in indoor

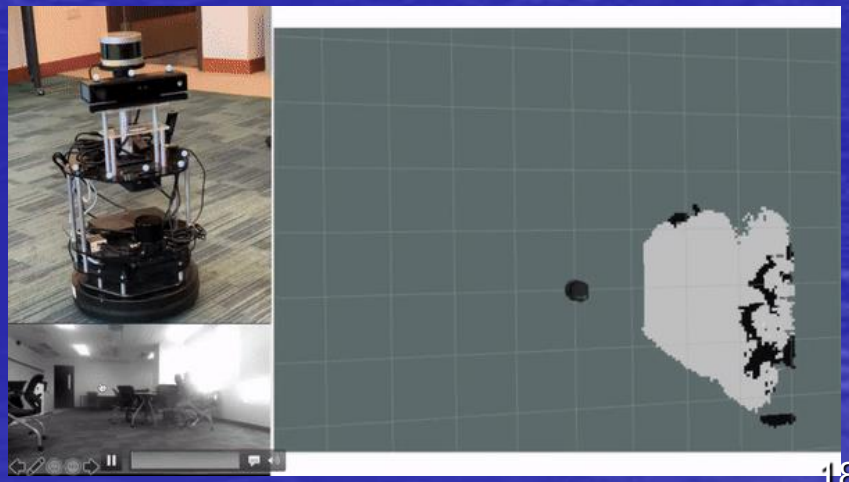




Local Infrastructure-Free sensors

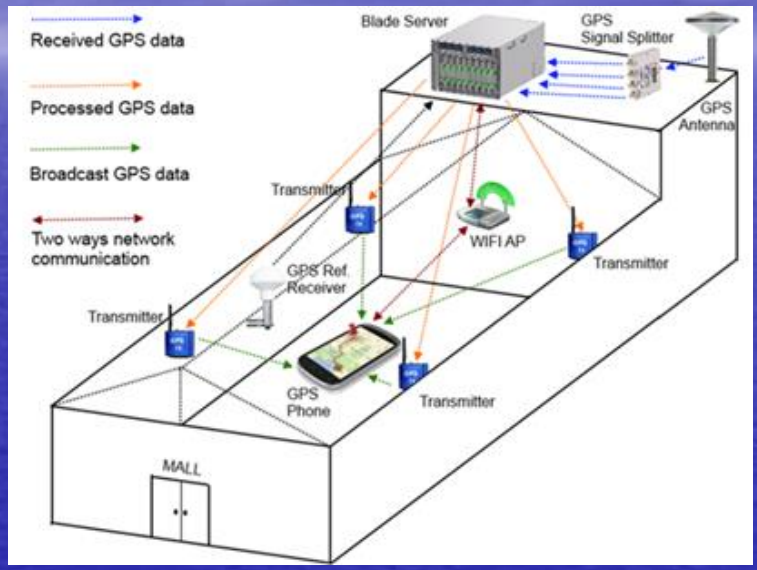
- GNSS
- Inertial Sensors
- Magnetometer
- Barometer (relative height)
- Camera
- Lidar/Ranging
- RGB-D

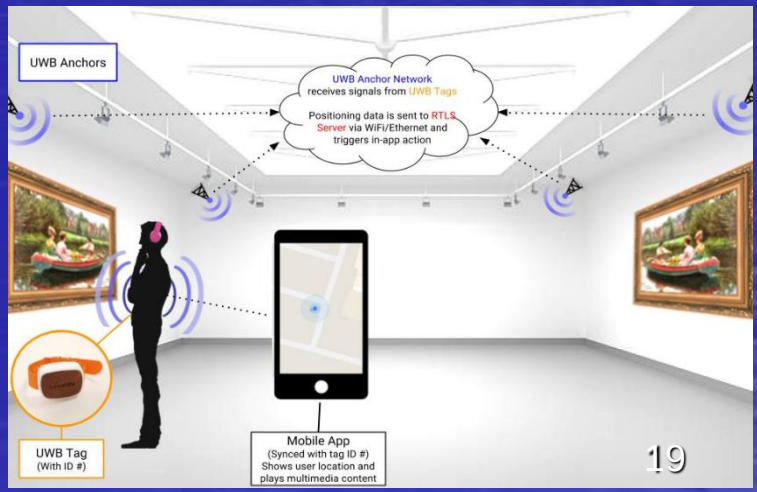




Local Positioning Infrastructure

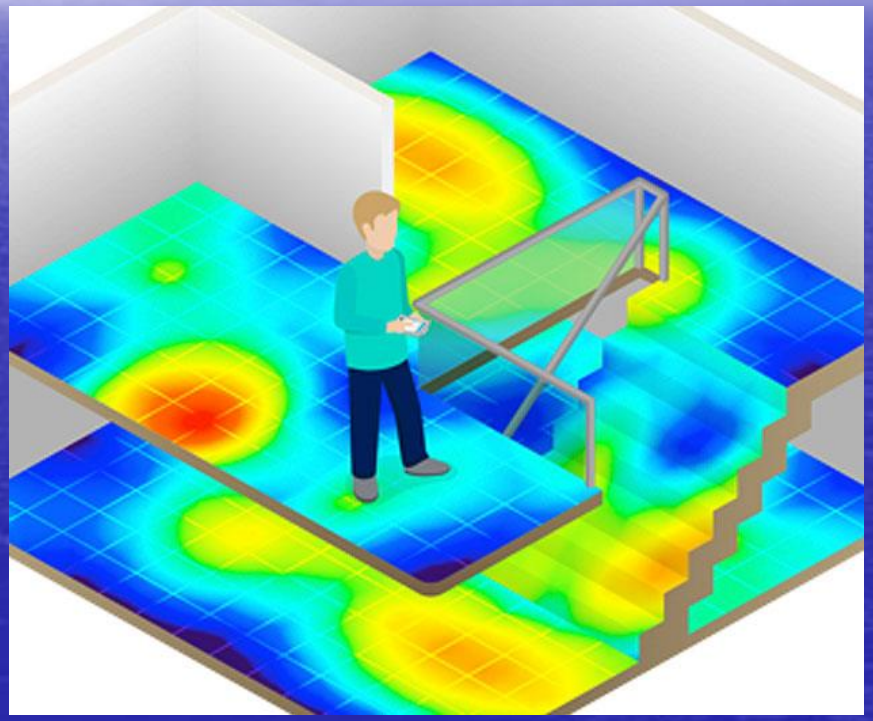
- Indoor GNSS/Pseudolite
- UWB
- BLE
- WiFi RTT
- Zigbee
- Cricket/Acoustic ranging
- 4/5/6G signals





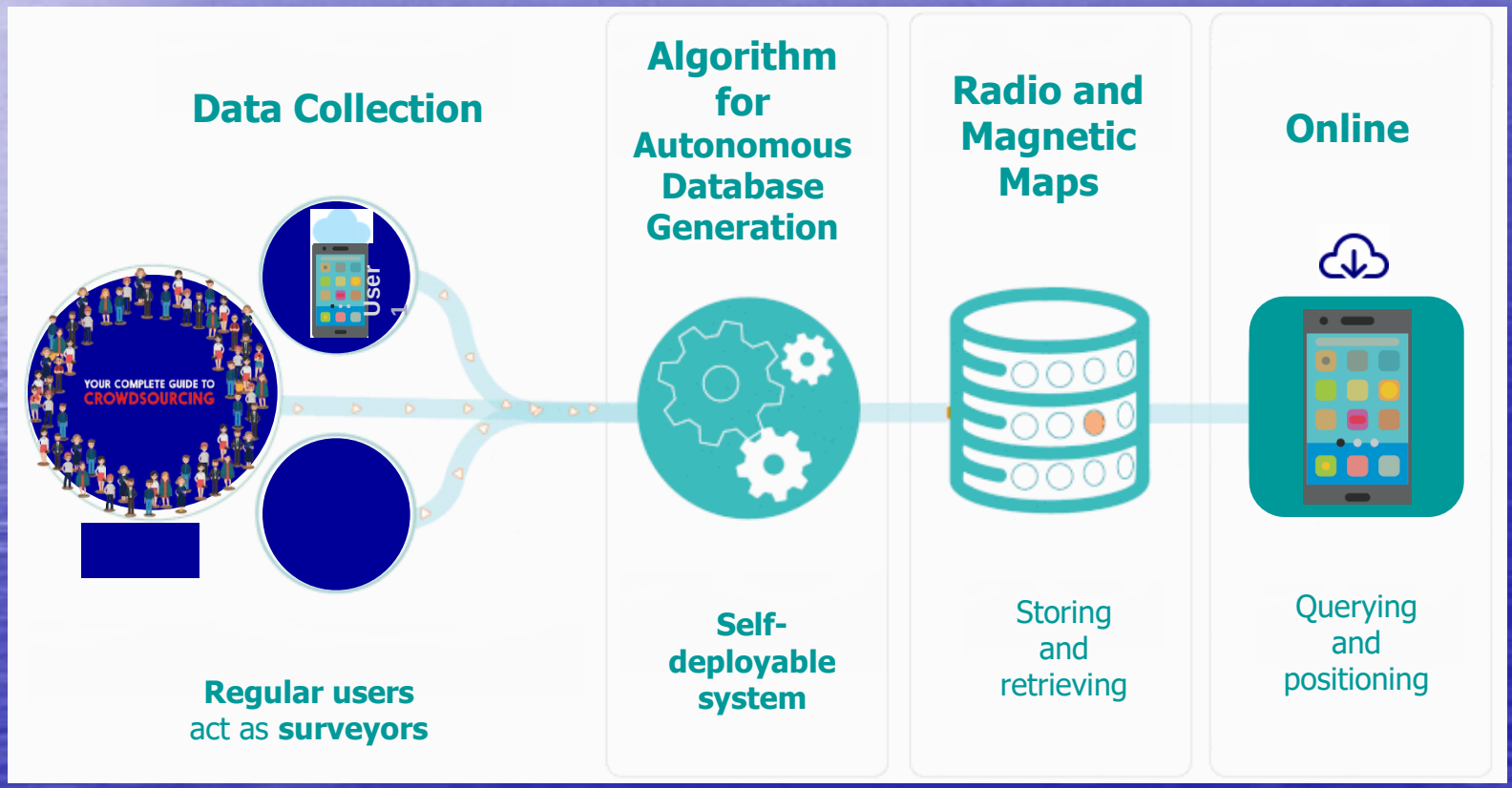
Signal of Opportunity: supported by other information

- Magnetic field
- Gravity field
- WiFi
- BLE
- Radio Signals
- 4/5/6G signals
- Barometer (absolute height)

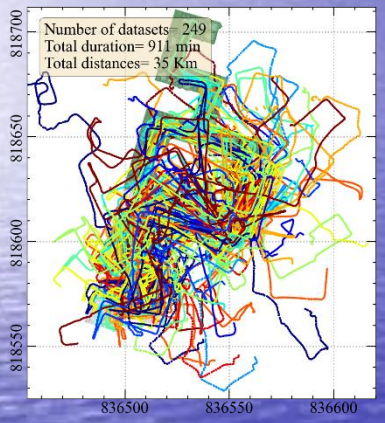


Accuracy is determined by the gradient of signal strength

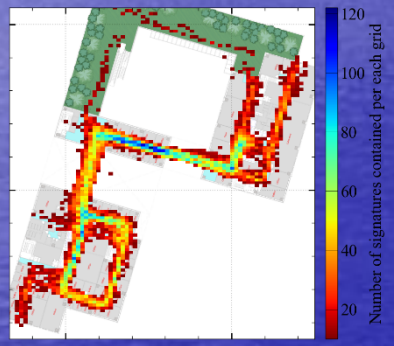
How to obtain RSS map?
Crowd Sourcing



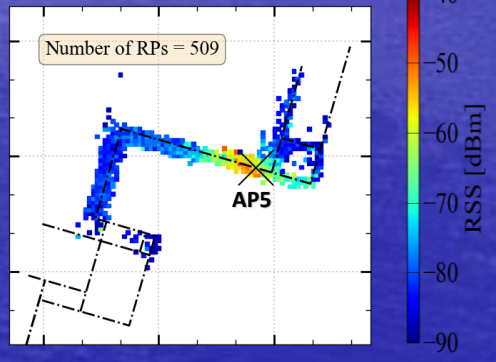
Map Generation: Radio/Magnetic map



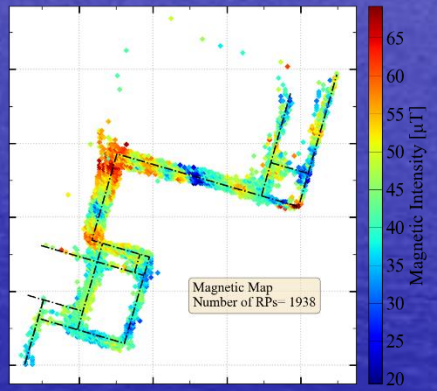
Raw Crowdsourced Data



Generated Grids with Signatures in the Floor Plan



Generated Radio Map for One Access Point



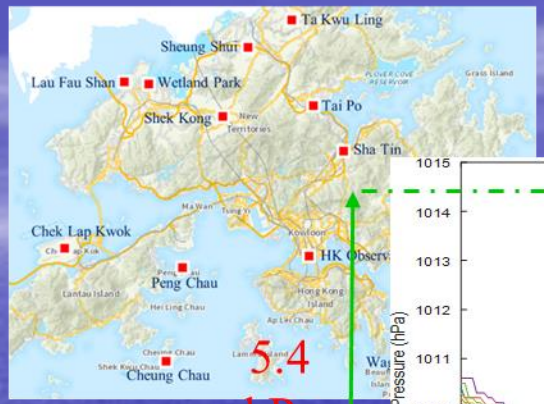
Generated Magnetic Map

Meteorological stations as a Positioning infrastructure

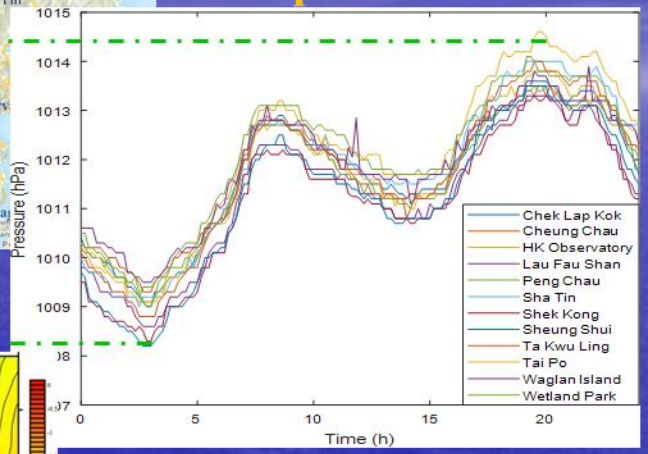
- Pressure can be used for height measurement

$$h = \frac{T_0}{C}\left(\left(\frac{P_r - \Delta P}{P_0}\right)^{-\frac{R \cdot C}{g_0 \cdot M}} - 1\right)$$

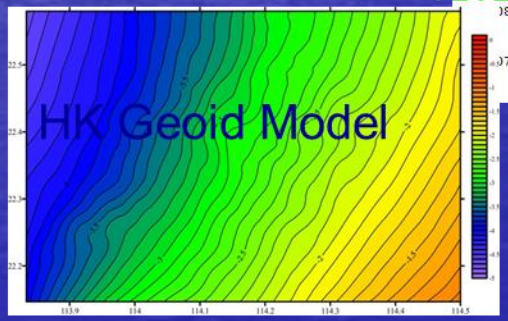
- Meteorological station data: P_0
- Geoid Model: ΔP
- One Meter accuracy for height with phones (indoor/outdoor)
  - Much better than GNSS

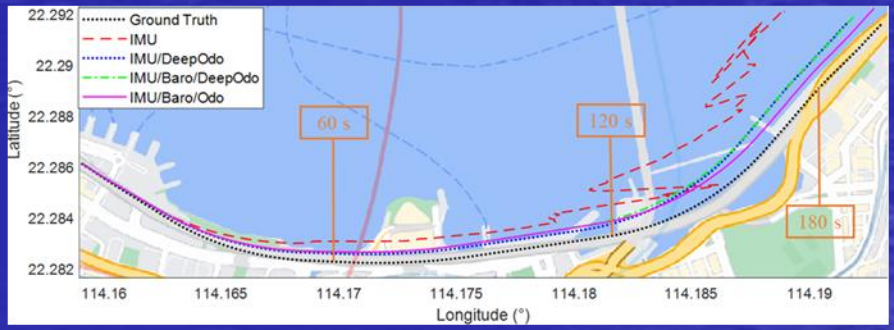


MSL pressures



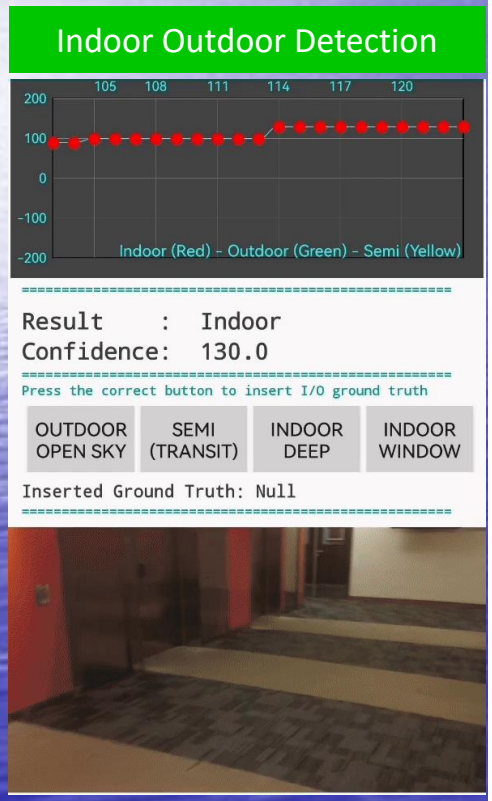
Changing Rate: 0.1 hPa/10 min

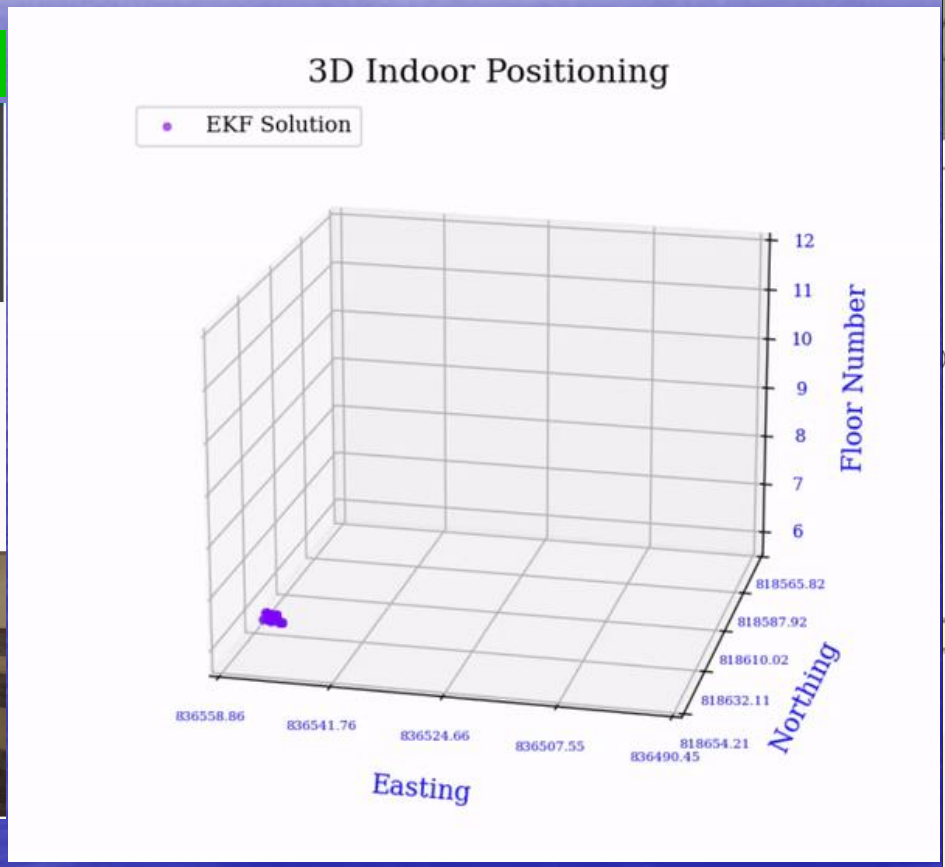




Smartphone positioning for vehicles with Barometer

Indoor-Outdoor Seamless Positioning With RSSI Maps



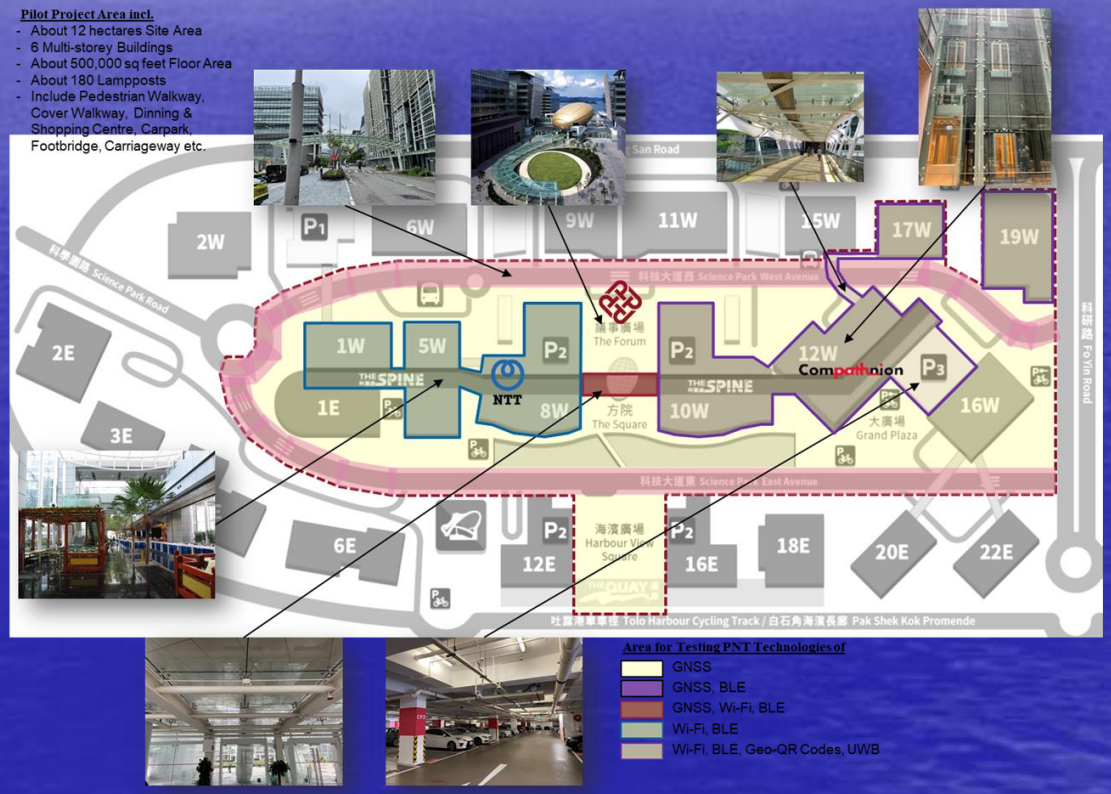


Hong Kong Smart Lamppost Project

- One of Hong Kong Smart City initiatives
- Multiple functions: monitoring, communication, positioning

Hong Kong Seamless Positioning Testbed

- Evault the performance of different positioning technologies
  - Outdoor: 5 m
  - Indoor: 2 m
- Uniformed interface for users



Resilient PNT Services

Dictionary

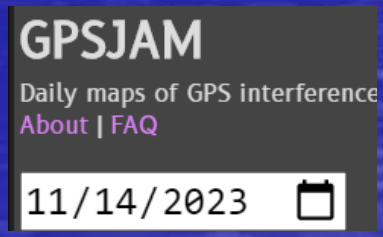
- the capacity to withstand or to recover quickly from difficulties; toughness.
- the ability of a substance or object to spring back into shape; elasticity.

Resilient PNT services

- Ability to tolerate partial failures
  - Detect failures (Integrity?)
    - Time to alarm
  - Isolation and Alternative Systems
    - Tolerant Performance
  - Recovery from failures
    - Fast recovery

GNSS Vulnerabilities

- System failure
  - Wrong message
  - Wrong signals
- Unintentional Interference
  - Radio Frequency Interference (RFI)
  - Ionosphere; Solar Max
  - Spectrum Congestion
- Intentional Interference
  - Jamming
  - Spoofing – Counterfeit Signals
- Human Factors
  - User Equipment & GPS SV Design Errors
  - Lack of Knowledge/Training
  - Over-Reliance

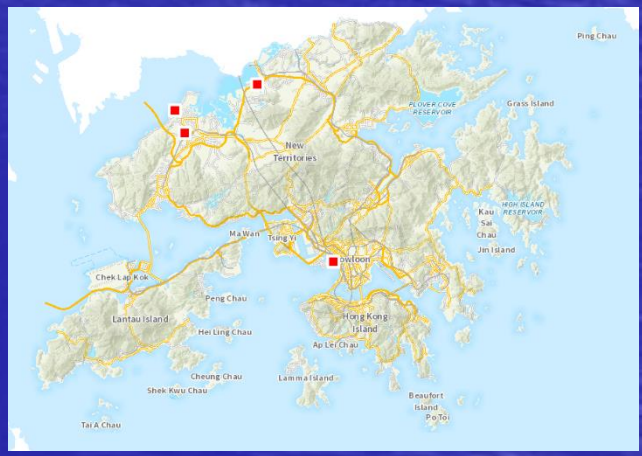


https://gpsjam.org/?lat=40.67241&lon=45.21150&z=1.8&date=2023-11-14

- Attacking GNSS signals is the easiest way to disturb economic activities in a region.
- Without GNSS PNT services
  - Power system interruption
  - Mobile communication networks
  - Financial Systems
  - ……

Examples

- Interruption of BBC digital broadcasting
  - 26 Jan. 2016, Malfunction of GPS satellites
  - BBC digital broadcasting in many regions was out of services for two days
  - The anomaly was also detected in electrical power grids
- In Hong Kong
  - HK$1 million in damage caused by GPS jamming that caused 46 drones to plummet during Hong Kong show
  - Reported GNSS Jamming cases in UAV surveying



Examples

Explainer | What happened to Hong Kong's pre-National Day drone show? The Post talks solar storms

Consultant working with organisers attributes decision to significant ionospheric interference affecting GPS signals used to control drones

Reading Time: 3 minutes

Why you can trust SCMP

Listen

Additional flight delays and magnetospheric–ionospheric disturbances during solar storms

Y. Wang, X. H. Xu, F. S. Wei, X. S. Feng, M. H. Bo, H. W. Tang, D. S. Wang, L. Bian, B. Y. Wang, W. Y. Zhang, Y. S. Huang, Z. Li, J. P. Guo, P. B. Zuo, C. W. Jiang, X. J. Xu, Z. L. Zhou & P. Zou

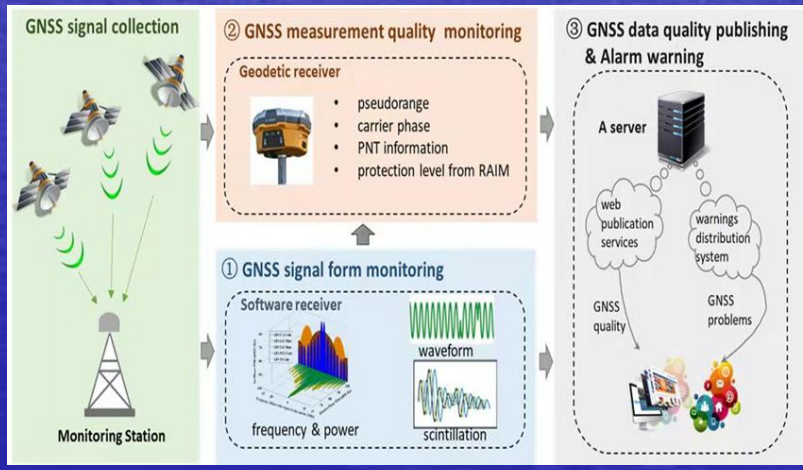
Scientific Reports **13**, Article number: 3246 (2023) | Cite this article

Abstract

Although the sun is really far away from us, some solar activities could still influence the performance and reliability of space-borne and ground-based technological systems on Earth. Those time-varying conditions in space caused by the sun are also called solar storm or space weather. It is known that aviation activities can be affected during solar storms, but the exact effects of space weather on aviation are still unclear. Especially how the flight delays, the top topic concerned by most people, will be affected by space weather has never been thoroughly researched. By analyzing huge amount of flight data (~ 4×10^6 records), for the first time, we quantitatively investigate the flight delays during space weather events. It is found that compared to the quiet periods, the average arrival delay time and 30-min delay rate during space weather events are significantly increased by 81.34% and 21.45% respectively. The

Resilient PNT Services

- Without rely on any single system
- Quality Monitoring of the performance
- Utilize any usable PNT sources, to generate optimal, seamless, reliable and stable PNT information
  - Diversified PNT Sources available
    - GNSS
    - Any radio signals
    - Image/Lidar based sensors
    - IMU
    - Magnetic field
    - Barometer
    - Maps
    - ……
- High level system design and standard are important



Current Status: Ubiquitous Positioning

- Great success on pedestrian and vehicle navigation (smartphone/vehicle navigation unit), Map Matching
  - But indoor navigation is still a problem
- Safety Critical applications need more efforts
  - Autonomous vehicle
  - UAV

Challenge 1: Indoor Environment Mapping

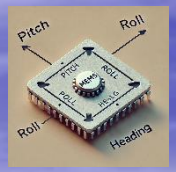
- Maps
  - Indoor map
  - RSS map
  - Address (POI)
- Very Costly
- Privacy
- Crowd Sourcing?
- Data Sharing?

Challenge 2: Reduce installation cost for resilient services

- Many technologies available, how many will be survived in future?
- Who will pay for positioning?
  - Why WiFi is widely available
- Improve Infrastructure-Free sensor performance/cost

MEMS Gyroscopes

Mechanical Gyroscope



MEMS Gyroscope

Current Status:

MEMS gyroscopes have achieved 0.1°/h level bias stability.

Future Development:

The 4th-generation gyroscope, based on atomic spin nuclear magnetic resonance, is expected to deliver laser gyroscope-level precision within the compact size of MEMS technology, achieving bias stability of <0.01°/h.

Main Application Areas and Key Specifications of Various Gyroscopes

Category	Navigation Grade	Tactical Grade	Industrial Grade	Consumer Grade
Application Areas	Aerospace, Long-duration UAV	High-end Industrial (Inspection, Resource Exploration), Annual Output Aircraft	Vehicle, Industrial Robot	Smartphones, Quadcopter drone
Bias Stability (°/h)	<0.1	0.1 - 1	1 - 15	> 15
GNSS-Denied Navigation Time	Several hours	<10 min	<1 min	-
Core Technologies	Laser Gyroscope, Fiber Optic Gyroscope, **MEMS Gyroscope**	**MEMS Gyroscope**	**MEMS Gyroscope**	**MEMS Gyroscope**
Price (USD)	> $100,000	$5000–$50,000	$100–$1,000	<10

Challenge 3: High Integrity/Resilient PNT service

- GNSS+ other systems (CPNT/APNT, local or global coverage)
  - LEO satellites (wider bandwidth)
  - Different local/regional systems proposed
  - Precise timing signal can significantly reduce cost
- Integrity for decimetre level requirement
- Regional/local quality monitoring

Summary

- Significant improvements on PNT services
  - From professionals to ordinary people
- GNSS provides global coverage with very low cost to users
  - Vulnerability of GNSS is well known
- Regional/Local PNT services are needed
  - Seamless and resilient PNT services
  - Local infrastructures/Signal opportunity
- Crowd sourcing/data sharing
  - Reduce the implementation cost

Thank