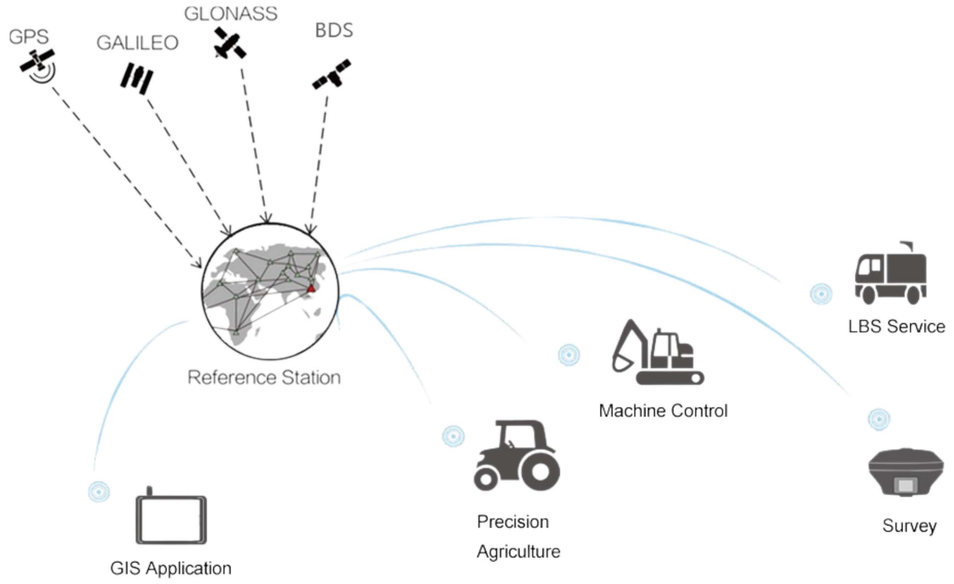
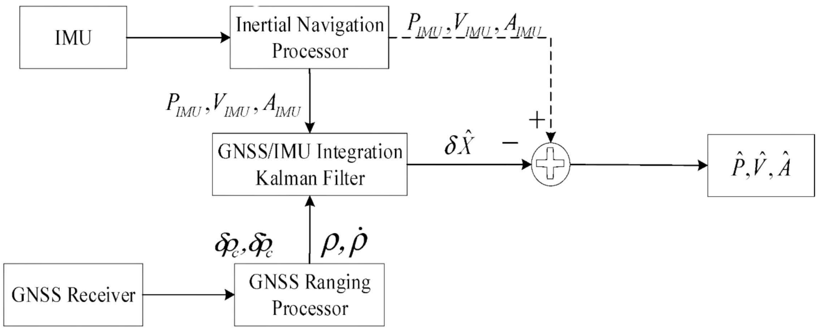
COURSE MATERIAL :

APPLICATIONS OF GNSS

BSc Surveying Sciences
Year IV Semester I
Department of Surveying & Geodesy
Faculty of Geomatics
Sabaragamuwa University of Sri Lanka 70140 Belihuloya





Curricula Enrichment delivered through the Application of Location-based Services to Intelligent Transport Systems (LBS2ITS)

Erasmus+
Co-funded by the Erasmus+ Programme of the European Union

Module Description: Today, GNSS is being increasingly used for many commercial applications in transportation, autonomous vehicles, machine control, marine navigation and other industries such as agriculture, where efficiencies can be improved from the application of precise, continuously available position and time information. This course introduces students to the theory and concepts of GNSS integration with other sensors, its applications, smartphone positioning and alternative positioning navigation & timing (APNT) systems.

This module has designed for the BSc (Surveying Sciences)(Surveying & Geodesy) programme for the Faculty of Geomatics, Sabaragamuwa University of Sri Lanka and will be offered in the fourth year first semester.

Learning Objectives:

- Describe the GNSS based PNT solutions in various land surveying applications.
- Analyse the concepts of GNSS and inertial navigation systems (INS) integration.
- Evaluate the various PNT solutions in various non-surveying applications.
- Execute a simple PNT solution development by integrating GNSS.
- Describe the development of autonomous navigation solutions.
- Create a PNT solution based on smartphone positioning.
- Describe the multi-sensory positioning concept.
- Evaluate the various alternative PNT technologies.

Key Contents:

- Review of GNSS PNT and GNSS Error mitigation
- Applications in Surveying
- Applications in Transportation
- Inertial Navigation Systems
- Sensor Integration for PNT
- GNSS in Engineering Applications and Machine Control
- GNSS in Precision Agriculture
- Marine and Aircraft Navigation Applications
- GNSS in spacecraft navigation
- GNSS in weather modelling
- GNSS in Earth observation applications
- Positioning with Smartphone
- Sensor fusion and Multi-Sensor positioning
- APNT Technologies

Practical Component: By completing this module, students will gain the technical proficiency to apply GNSS in professional surveying practices, providing accurate spatial data for a wide range of projects, including construction, land development, and geodetic surveys. The given practical case studies will simulate professional surveying scenarios, where students apply their theoretical knowledge to solve complex spatial problems using GNSS technologies. Further, there are several problem based and collaborative learning tasks on ‘GNSS applications in surveying’, ‘GNSS NMEA data integration’ and ‘Smartphone Positioning & QGIS’ in this module.

SG41313 - Applications of GNSS

Year IV Semester I

BSc (Surveying Sciences)(Surveying & Geodesy)

M.D.E.K. Gunathilaka*(PhD, MRICS)*
Department of Surveying & Geodesy, Faculty of Geomatics

erandakan@geo.sab.ac.lk

Applications of GNSS
Lecture #1

Introduction: GNSS Infrastructure & Survey Applications

SG41313 – Applications of GNSS

Lecturer : M.D.E.K. Gunathilaka (PhD,MSc,BSc)
Lectures : 30 hours of Lectures
Practical : 45 hours
Credit : 03

Evaluation;

Final Exam 50%
Continues Assessments 50%
Class room 30%
Practical 20%

Course Content;

- Introduction on GNSS Positioning?
- Inertial Navigation.
- Baseline Processing (single & network).
- GNSS Quality Control.
- Navigation Applications of GNSS (marine, aviation, land, space).
- Other Scientific Applications (TEC, weather, etc).
- Future developments on GNSS (GNSS Modernization).

Intended Learning Outcomes (ILOs);

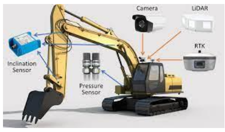
- ✓ **Describe the various error sources effect to GNSS positioning accuracy.**
- ✓ **Explain how to minimize them.**
- ✓ **Compare the Code vs. Carrier based positioning.**
- ✓ **Explain the GNSS aided INS applications.**
- ✓ **Describe various GNSS applications.**
- ✓ **Establish GNSS control points.**
- ✓ **Describe how the GNSS can be used for other applications.**
- ✓ **Name various developments related to GNSS.**

Applications of GNSS

- ✓ Navigation
- ✓ Timing
- ✓ Logistics
- ✓ Surveying
- ✓ Precession Agriculture
- ✓ Machine Automation
- ✓ Military

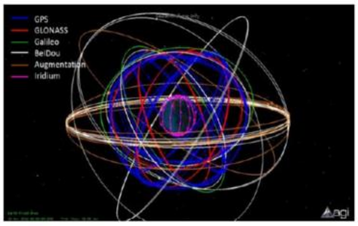


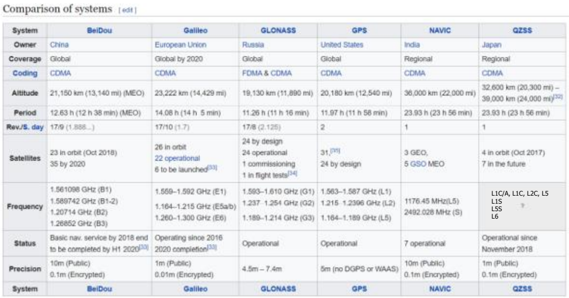




GNSS - Global Navigation Satellite Systems

GPS, GLONASS, Galileo, BeiDou/COMPASS





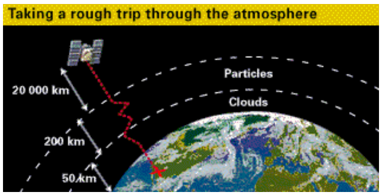
Comparison of systems [edit]

System	BeiDou	Galileo	GLONASS	GPS	NAVIC	QZSS
Owner	China	European Union	Russia	United States	India	Japan
Coverage	Global	Global by 2020	Global	Global	Regional	Regional
Coding	CDMA	CDMA	FDMA & CDMA	CDMA	CDMA	CDMA
Altitude	21,150 km (13,140 mi) (MEO)	23,222 km (14,429 mi)	19,130 km (11,890 mi)	20,180 km (12,540 mi)	36,000 km (22,000 mi)	32,600 km (20,300 mi) – 39,000 km (24,000 mi)[32]
Period	12.63 h (12 h 38 min) (MEO)	14.08 h (14 h 5 min)	11.26 h (11 h 16 min)	11.97 h (11 h 58 min)	23.93 h (23 h 56 min)	23.93 h (23 h 56 min)
Rev./S. day	17/9 (1.888...)	17/10 (1.7)	17/8 (2.125)	2	1	1
Satellites	23 in orbit (Oct 2018) 35 by 2020	26 in orbit 22 operational 6 to be launched[33]	24 by design 24 operational 1 commissioning 1 in flight tests[34]	31,[35] 24 by design	3 GEO, 5 GSO MEO	4 in orbit (Oct 2017) 7 in the future
Frequency	1.561098 GHz (B1) 1.589742 GHz (B1-2) 1.20714 GHz (B2) 1.26852 GHz (B3)	1.559–1.592 GHz (E1) 1.164–1.215 GHz (E5a/b) 1.260–1.300 GHz (E6)	1.593–1.610 GHz (G1) 1.237–1.254 GHz (G2) 1.189–1.214 GHz (G3)	1.563–1.587 GHz (L1) 1.215–1.2396 GHz (L2) 1.164–1.189 GHz (L5)	1176.45 MHz(L5) 2492.028 MHz (S)	L1C/A, L1C, L2C, L5 L1S L5S L6
Status	Basic nav. service by 2018 end to be completed by H1 2020[33]	Operating since 2016 2020 completion[33]	Operational	Operational	7 operational	Operational since November 2018
Precision	10m (Public) 0.1m (Encrypted)	1m (Public) 0.01m (Encrypted)	4.5m – 7.4m	5m (no DGPS or WAAS)	10m (Public) 0.1m (Encrypted)	1m (Public) 0.1m (Encrypted)
System	BeiDou	Galileo	GLONASS	GPS	NAVIC	QZSS

What are the elements/components of a GNSS?

Errors in GNSS

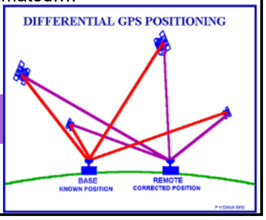
- ✓ Satellite Clock
- ✓ Orbit/Ephemeris Errors
- ✓ Ionospheric Delay
- ✓ Tropospheric Delay
- ✓ Receiver Noise
- ✓ Multipath



GNSS Infrastructure: Why DGNSS?

- ✓ DGNSS provides improved location accuracy (Code based)
- ✓ Relies on single or a network of fixed ground reference stations.
- ✓ Rover stations may correct their pseudo ranges by the same amount.
- ✓ Baseline can be 100km away
- ✓ Propagation & Clock errors are estimated…!
- ✓ Accuracy: <1m RT & mm in PP.

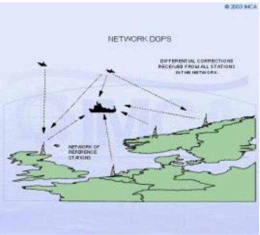
- **Closer Area (Single DGPS)**
- **Large Area DGPS (GBAS & SBAS)**



GNSS Infrastructure: GBAS

✓Relies on a network of fixed reference stations.

✓ Errors are modelled & weights can assign for each station, distance, quality, etc...



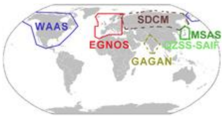
Communication: Radio, GPRS/NTRIP

GNSS Infrastructure: SBAS

✓The network corrections are uplink to geo stationary satellites and broadcast over the region (satellite based).

✓Provides improved location accuracy over an entire region…!

✓Starfix, OmniSTAR, Atlas, EGNOS, MSAS, GAGAN, etc



Tropo, Iono models; weighted solution.

Some systems transmit additional information about errors (clock drift, ephemeris, ionospheric delay, etc) >> more accurate.

Group Assignment:

Make presentations on each SBAS.

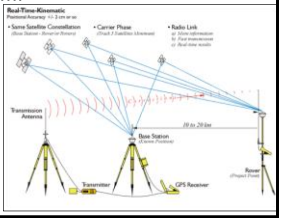
(It's operational architecture, technical aspects, coverage, accuracy, etc)

GNSS Infrastructure: RTK

- ✓ Use carrier phase tracking…!

- ✓ Relies on single or a network of fixed ground reference stations.
- ✓ The integer ambiguity is solved at the rover with the data from the Base…
- ✓ Corrections are broadcasted…
- ✓ Propagation errors are estimated…!

- **Telemetry: Radio modems (UHF), GPRS/NTRIP**
- **5-10* cm**

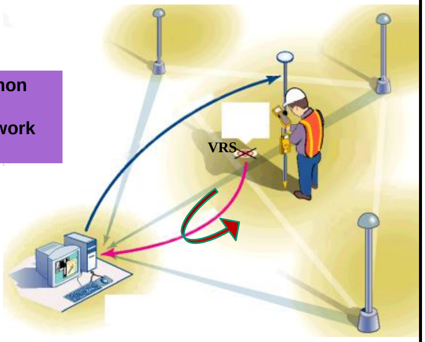


Network RTK & VRS

- ✓ Accuracy of RTK decrease when exceeding the distance threshold (15 to 20 km) due to limited range.
- ✓ The VRS technique is based on having a network of GNSS.
- ✓ These regional area corrections are used to interpolate a mathematical model for the ionosphere, troposphere and ephemeris distortions for the user's location enclosed by the base stations (grid based).
- ✓ This mathematical model is then used to create a VRS…

Network RTK & VRS

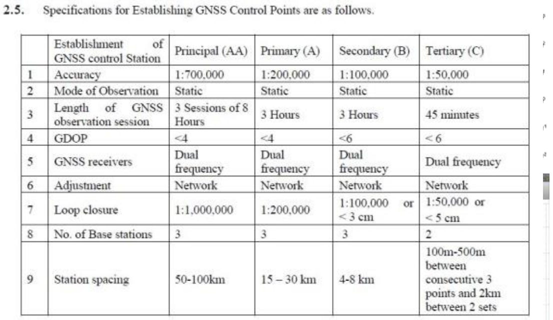
At least 5 common satellites
Minimum 3 network stations…



CORS networks

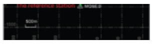
GNSS Applications in Surveying

1. Control Establishment



2.5. Specifications for Establishing GNSS Control Points are as follows.

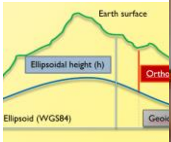
	Establishment of GNSS control Station	Principal (AA)	Primary (A)	Secondary (B)	Tertiary (C)
1	Accuracy	1:700,000	1:200,000	1:100,000	1:50,000
2	Mode of Observation	Static	Static	Static	Static
3	Length of GNSS observation session	3 Sessions of 8 Hours	3 Hours	3 Hours	45 minutes
4	GDOP	<4	<4	<6	< 6
5	GNSS receivers	Dual frequency	Dual frequency	Dual frequency	Dual frequency
6	Adjustment	Network	Network	Network	Network
7	Loop closure	1:1,000,000	1:200,000	1:100,000 or < 3 cm	1:50,000 or < 5 cm
8	No. of Base stations	3	3	3	2
9	Station spacing	50-100km	15 – 30 km	4-8 km	100m-500m between consecutive 3 points and 2km between 2 sets



2. Topographic Data Collection

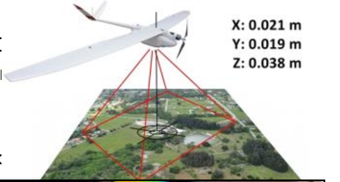
- ✓ RTK - Single Base (Radio)
- ✓ RTK –Network/CORS
- ✓ Some Hints (distance & field conditions)
- ✓ Position and Heights/contouring..
- ✓ Tilt/IMU

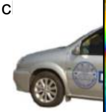
Geoid/EGM models

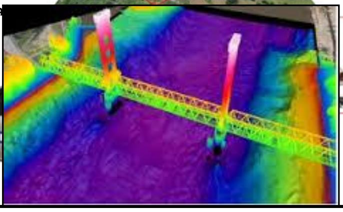


3. Navigation (Hydrographic/ Drone/ LIDAR)

- ✓ DGNSS for controls (
- ✓ RTK for navigation/co
- ✓ Single Base
- ✓ Network/CORS
- ✓ Some Hints (field con
- ✓ 3D Positioning (V da
- ✓ PPK/OTF
- ✓Time-sync





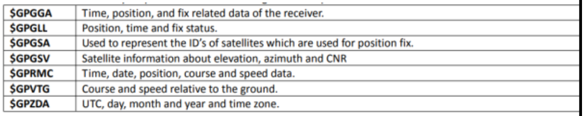


Data Formats…

RINEX – Raw GNSS data

RTCM – GNSS corrections

NMEA – Positioning Data



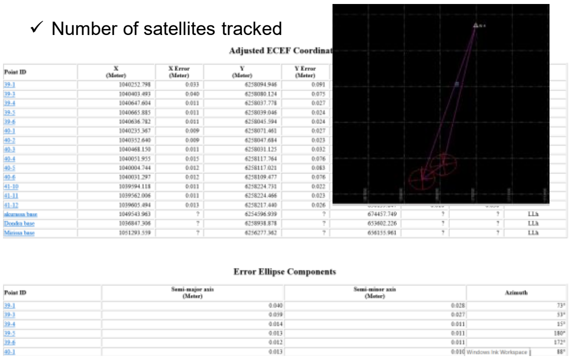
$GPGGA	Time, position, and fix related data of the receiver.
$GPGLL	Position, time and fix status.
$GPGSA	Used to represent the ID's of satellites which are used for position fix.
$GPGSV	Satellite information about elevation, azimuth and CNR
$GPRMC	Time, date, position, course and speed data.
$GPVTG	Course and speed relative to the ground.
$GPZDA	UTC, day, month and year and time zone.

GLL - Geographic Position, Latitude / Longitude and time.

eg1. **$GPGLL,4916.45,N,12311.12,W,225444,A**
4916.46,N Latitude 49 deg. 16.45 min. North
12311.12,W Longitude 123 deg. 11.12 min. West
225444 Fix taken at 22:54:44 UTC A Data valid

GNSS data QA & QC.

- ✓ Number of satellites tracked



Adjusted ECEF Coordinat

Point ID	X (Meter)	X Error (Meter)	Y (Meter)	Y Error (Meter)				
39-1	1040252.798	0.033	6258094.946	0.091				
39-3	1040403.493	0.040	6258080.124	0.075				
39-4	1040647.604	0.011	6258037.778	0.027				
39-5	1040665.885	0.011	6258039.046	0.024				
39-6	1040636.782	0.011	6258045.594	0.024				
40-1	1040235.367	0.009	6258071.461	0.027				
40-2	1040352.640	0.009	6258047.684	0.023				
40-3	1040468.150	0.011	6258031.125	0.032				
40-4	1040051.955	0.015	6258117.764	0.076				
40-5	1040004.744	0.012	6258117.021	0.083				
40-6	1040031.297	0.012	6258109.477	0.076				
41-10	1039594.118	0.011	6258224.731	0.022				
41-11	1039562.006	0.011	6258224.466	0.023				
41-12	1039605.494	0.013	6258217.440	0.026				
akaramsa base	1049543.963	?	6254596.939	?	674457.749	?	?	LLh
Dondra base	1036847.306	?	6258938.878	?	653602.226	?	?	LLh
Marissa base	1051293.559	?	6256277.362	?	656155.961	?	?	LLh

Error Ellipse Components

Point ID	Semi-major axis (Meter)	Semi-minor axis (Meter)	Azimuth
39-1	0.040	0.028	73°
39-3	0.059	0.027	53°
39-4	0.014	0.011	15°
39-5	0.013	0.011	180°
39-6	0.012	0.011	172°
40-1	0.013	0.010	88°

Thank You.

SG41313 – Applications of GNSS

Year IV - Semester I

2- DGNSS

MDEK Gunathilaka (PhD, MRICS)

DEPARTMENT OF SURVEYING AND GEODESY
FACULTY OF GEOMATICS

Why DGNSS…?

Basic GPS measurements consist of biased and noisy estimates of ranges to the satellites

The principal source of bias is the unknown receiver clock error, dT relative to the GPS time

The other remaining errors are:

- Satellite clock and ephemeris
- Ionospheric and tropopheric delays
- Multipath, receiver noise, etc

C/A-code based positioning (perhaps smoothed by carrier phase data):

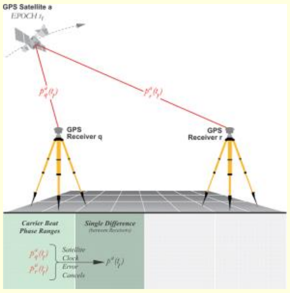
- Without S/A, $\sigma_{URE} \approx 6$m
- Horizontal (at 95% level) ≈ 10m
- Vertical (at 95% level) ≈ 15m

How to improve on these accuracy?

- Differential GPS (DGPS)!

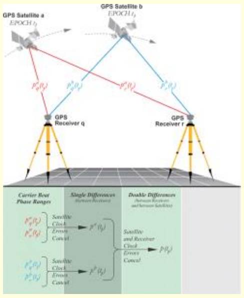
Range Errors are estimated with respect to the known station…!

DGNSS – Single Differencing



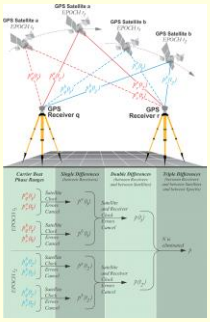
- Between Receiver Differencing.
- dt is zero as both receivers are observing the same satellite.
- The propagation and orbital errors are also almost same at both receivers.
- Remaining is receiver clock error (dT) and Ambiguity (N).

DGNSS – Double Differencing



- dT is eliminated by ‘between satellite differencing’.
- The propagation and orbital errors are also almost same.
- Only remaining is the Ambiguity (N).

DGNSS – Triple Differencing



- Integer Cycle Ambiguity (N) is estimated with the consecutive epochs...

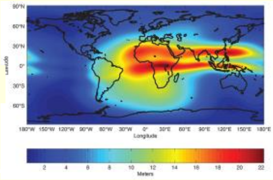
Why DGNSS…?

Taking advantage of the fact that;

Errors associated with satellite and the atmosphere are similar to users close together (sometimes could be up to hundreds of km!)

These errors vary ‘shortly’ with time

These errors exhibit temporal and spatial correlations



The closer the two users and the measurement epochs – the more similar the errors are

Decorrelated with the increase of distance and time

DGNSS…

Mathematical model for the code range

$$P = \rho + c.(dT - dt) + I + T + M_P + e_P$$

Where

- P is the observed range
- ρ is the geometric slant satellite-receiver range
- c is the speed of light in vacuum
- dT is the receiver clock bias
- dt is the satellite clock bias
- I is the ionospheric delay
- T is the tropospheric delay
- M_P is the pseudo-range multipath
- e_P is the code observation noise.

DGNSS…

If the position of a GPS receiver (the reference station) is accurately known:

The combined effect of the errors can be estimated for each receiver-satellite range measurements (called the differential correction, PRC)

These error estimates can then be made available to other GPS users within the area

Other GPS users (the rovers) can apply these PRCs and PRCdots to their measurements (within lapse of time) to mitigate their errors and improve the accuracy of their position estimation

DGNSS…

Examining pseudorange measurement from a reference station (r) to a single satellite (s):

- $\rho_r = r_r + c(\delta t_r - \delta t^s) + I_r + T_r + \varepsilon_r$

The geometric range to a satellite from the reference station is computed as:

- $R_r = || x^s - x_r||$

Where x^s is the satellite position obtained from the navigation message and x_r is the known position of the reference station

The error in ρ_r, pseudorange measured at the reference station is:

- $e_r = r_r - \rho_r$
- $\quad = -c(\delta t_r - \delta t^s) - I_r - T_r - \varepsilon_r$
- Note: this is the differential correction, PRC, computed at the reference station and broadcasted to other users

DGNSS…

On the rover (u) side which measures pseudorange to the same satellite (s):

- $\rho_u = r_u + c(\delta t_u - \delta t^s) + I_u + T_u + \varepsilon_u$

The differently corrected pseudorange measurement of the rover will be:

- $\rho u = \rho_u + e_e$
- $\quad = r_u + c(\delta t_u - \delta t_r) + (I_u - I_r) + (T_u - T_r) + \varepsilon_u + \varepsilon_r$
- $\quad = r_u + c(\delta t_u - \delta t_r) + \varepsilon_{ur}$

The satellite bias term will be similar on both receivers, hence cancelled out

If the distance and latency is not ‘too long’,

- The ephemeris error would be common
- The ionospheric and tropospheric would be quite common

However, errors introduced by both receivers noise as well as multipath on both sides will be reprieve the accuracy as indicated in the ε_{ur}

DGNSS Applications.

If high accuracy is required, post processed DGNSS is applied.
eg. Control point establishment.

Here, the PR equation is solved by least squire estimation and mm accuracy can be obtained.

$$\mathbf{P = \rho + c.(dT - dt) + I + T + M_P + e_P}$$

$$\mathbf{Ax} = \mathbf{b} \quad \Longrightarrow \quad \mathbf{x} = \left(\mathbf{A}^T\mathbf{A}\right)^{-1}\mathbf{A}^T\mathbf{b}$$

DGNSS Applications.

In navigation applications – these error corrections is needed in <u>real-time</u> – <u>communication (radio) link is needed!</u>

In practice, some delay will occurs in the rovers the corrections – <u>latency</u>

The closer the rovers to the reference station and the shorter the latency time – the more accurate the correction

Data Communication

TCP/IP

Used when reliability is more important than speed

UDP

Used when speed is more important than reliability

GSM

Good data integrity, paid with latency; reliability depends on service provider coverage

Radio

Very good data integrity, low latency. High system reliability. Application limited by infrastructure diffusion (DAB/DARC, private radio link)

Data Communication

RTCM-104 (Radio Technical Commission for Maritime Services)

Differential corrections

NMEA National Marine Electronics Association

Used to transmit GPS information from the receiver to hardware that uses the positioning as input

Real-time marine navigation

NMEA strings:

- $GPGGA – GPS fix data message (lat, long, time, #SVs, etc)
- $GPGGL – Geographic position (lat, long, time)
- $GPGSA – GPS DOP and active satellites (SVs, P, H, VDOP)
- $GPGSV – GPS satellites in view (SV elevation/azimuth, SNR, etc.)
- $GPVTG – GPS velocity and heading
- $GPZDA – Time & Date message

- DGNSS
  - Single Base line
  - Network
  - WAAS/ SBAS/ GBAS

Next: RTK

Thank You.

SG41313 – Applications of GNSS

Year IV - Semester I

3-RTK GNSS

MDEK Gunathilaka (PhD, MRICS)

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Why …?

To minimise the effects due to errors in GNSS…

RTK – **Real Time Kinematic** and is a technique that uses **carrier-based ranging.**

It is more precise than those available through code-based positioning in real time applications.

However, RTK technique is complicated.

RTK is used for applications that require higher accuracies (on the go/ real time), such as centimetre-level positioning, up to 1 cm + 1 ppm accuracy.

Errors are estimated with respect to the Known/Base station.

RTK Range Calculation…

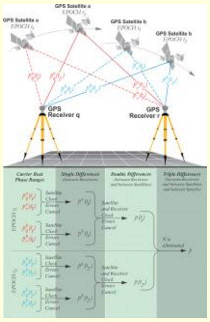
Range is calculated by determining the **number of carrier cycles** between the satellite and the GNSS antenna station, then multiplying this number by the carrier wavelength.

The period of the carrier frequency times the speed of light gives the wavelength, which is about 0.2 meters for the L1 carrier. With a 1% of wavelength accuracy in detecting the leading edge, this component of pseudorange error might be as low as 2 millimeters.
This compares to 3 meters for the C/A code and 0.3 meters for the P code.

The calculated pseudo ranges still include errors from such sources as satellite clock and ephemerides, and ionospheric and tropospheric delays.

To eliminate these errors and to take advantage of the precision of carrier-based measurements.
RTK performance requires corrections to be transmitted from the base station to the rover station, simultaneously.

RTK DGNSS – Triple Differencing



- Integer Cycle Ambiguity (N) is estimated with the consecutive epochs...

RTK Ambiguity Resolution…

$$d = n\lambda + \phi + e$$

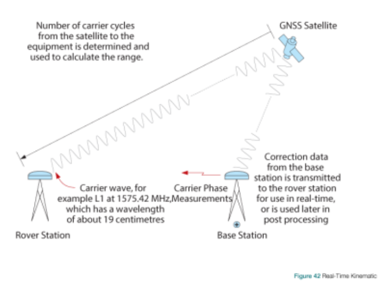


Figure 42 Real-Time Kinematic

RTK Ambiguity Resolution…

$$d = n\lambda + \phi + e$$

A process called “**ambiguity resolution**” (*determination of n*) is needed to determine the number of whole cycles.

The fractional wavelength measurement > require Phase Measurement

Least Square Estimation.

Initialization required

Ambiguity Fixed Solution

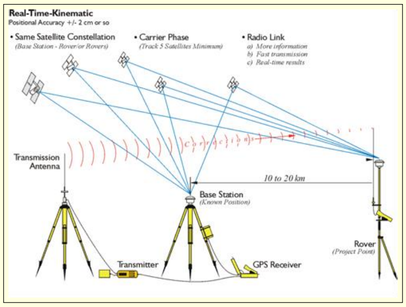
Ambiguity Float Solution

RTK Ambiguity Resolution…

The satellite carrier total phase can be measured with ambiguity as to the number of cycles.

$$\Phi_p^i(t) = c\,\tau_{p,\phi}^i + c\left(\Delta t^i(t_e) - \Delta t_p(t)\right) + \lambda N_p^i$$

Radio RTK …



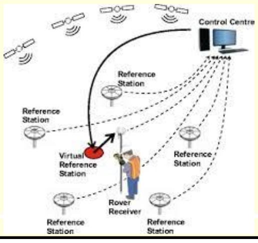
- **Telemetry: Radio modems (UHF), GeoSat, GPRS, NTRIP**
- **2-5* cm**

Network RTK …

Is based on the use of several widely spaced permanent stations.
Depending on the implementation, positioning data from the permanent stations is regularly communicated to a central processing station.

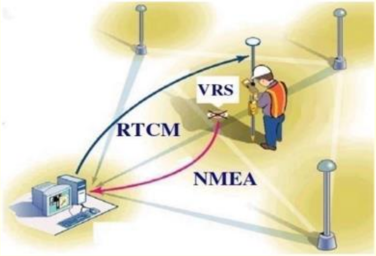
On demand from RTK user terminals, which transmit their approximate location to the central station, the central station calculates and transmits correction information or corrected position to the RTK user terminal.

Depending on the implementation, data may be transmitted over cellular radio links or other wireless medium.



Network RTK …

Why VRS..?



Continuously Operating Reference Station - CORS Network…

- **SL CORS**

RTK Applications.

Discussion…

https://www.youtube.com/watch?v=O-NF2LuLSnQ

Next: INS…

Thank You.

SG41313 – Applications of GNSS

Year IV - Semester I

4- Inertial Navigation System (INS)

MDEK Gunathilaka (PhD, MRICS)

DEPARTMENT OF SURVEYING AND GEODESY
FACULTY OF GEOMATICS

Discussion - Can GNSS handle all situations?

- **Tree canopy**
- **Inside a building**
- **Under a bridge/tunnel**
- **Outer space (other planets & Sun, etc)**
- **Underwater**

End users point of view;

- **Continuous performance**
- **Reliability**

Need some other devices as well; eg INS

What is INS…?

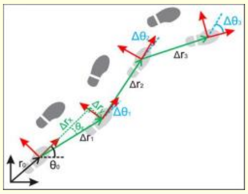
A navigation system developed using the basic parameters such as orientation, speed, acceleration, etc.

Form of Dead-Reckoning…
Is the process of calculating one's **current position** by using a **previously determined position** and advancing that position based upon known or **estimated speeds over elapsed time and course**.

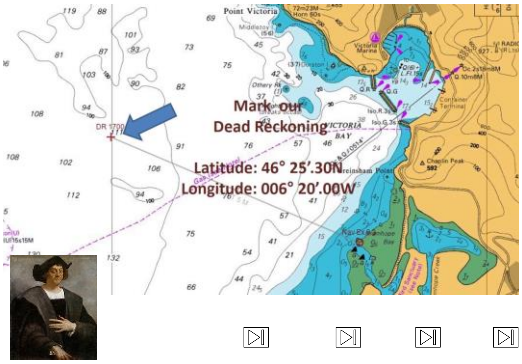
Involved additional sensors to measure these parameters continuously.
Eg. Gyroscopes/**Rotation sensors**, Motion sensors, **Accelerometers**, etc.

The real time position to be updated as the data comes/update with the help of a **computer processor**.

Otherwise, the estimated position could be erroneous due to **error accumulation**.



Dead Reckoning…?

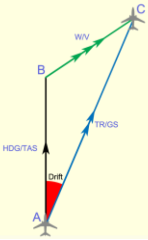


What is INS…?

This way, a continuous calculation of position is obtained by computation of the **orientation, velocity, direction, speed of movement**, etc of a moving object **with out the need of any external references.**

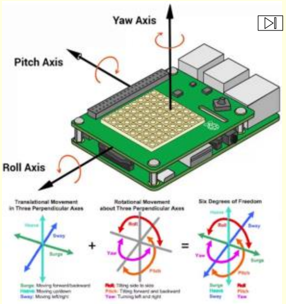
A self contained navigation technique. (based on the initial position, changes to the orientation and its speed).

Drift is the angle between the heading of the airplane and the desired track.
A is the last known position (fix). C is the air position
B is the DR position (usually shown with a triangle).



Components of an IMU…

Combines a 3-axis gyroscope and 3-axis accelerometer



Measuring Angular Velocities and Linear Accelerations respectively.

INS…

Calibration is essential in making accurate measurements…

The measured quantity (where the IMU is) and the required quantity (where the actual motion happens/required) will be different.

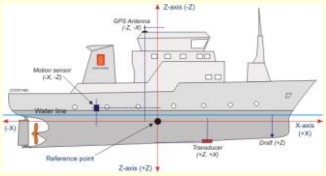
So, mathematical modelling is required…

Object Reference Point…

Inertial Reference frame …

Offset measurements….

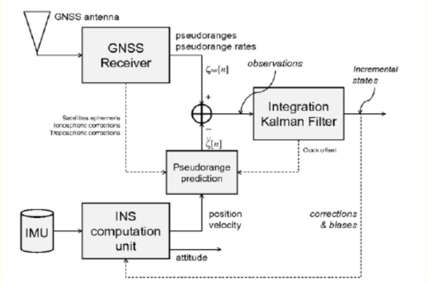
Alignment Test/ Calibration…



GNSS & INS Integration…

Not Relative anymore.

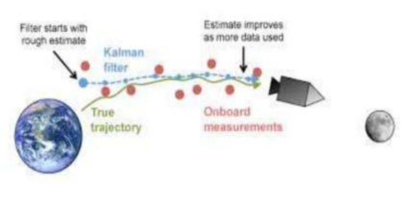
Very Accurate & Reliable…



GNSS & INS Integration…

Adaptive Filters (buffer for navigation time/distance) to smooth navigation… Kaman / furrier series..

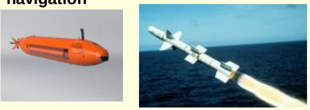
Kalman filter use algorithm that uses series of measurements that are observed over time and that contains statistical noise and other inaccuracies that are found in the system.



Predict a state, update with the observations, estimation of the noise.

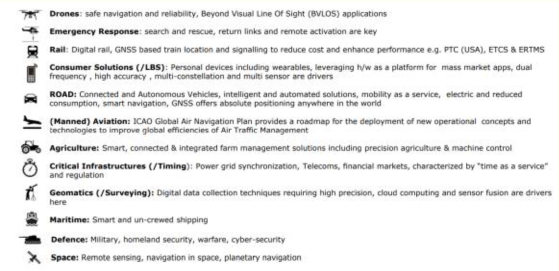
INS Applications.

- ✓Ship, Arial and Land vehicle navigation
- ✓Spacecraft navigation
- ✓Underwater navigation



- ✓Warfare weapons like missile guidance, UAV, ULV, etc.
- ✓ In Surveying…!

Next: GNSS (+ INS) Applications…



Drones: safe navigation and reliability, Beyond Visual Line Of Sight (BVLOS) applications

Emergency Response: search and rescue, return links and remote activation are key

Rail: Digital rail, GNSS based train location and signalling to reduce cost and enhance performance e.g. PTC (USA), ETCS & ERTMS

Consumer Solutions (/LBS): Personal devices including wearables, leveraging h/w as a platform for mass market apps, dual frequency , high accuracy , multi-constellation and multi sensor are drivers

ROAD: Connected and Autonomous Vehicles, intelligent and automated solutions, mobility as a service, electric and reduced consumption, smart navigation, GNSS offers absolute positioning anywhere in the world

(Manned) Aviation: ICAO Global Air Navigation Plan provides a roadmap for the deployment of new operational concepts and technologies to improve global efficiencies of Air Traffic Management

Agriculture: Smart, connected & integrated farm management solutions including precision agriculture & machine control

Critical Infrastructures (/Timing): Power grid synchronization, Telecoms, financial markets, characterized by "time as a service" and regulation

Geomatics (/Surveying): Digital data collection techniques requiring high precision, cloud computing and sensor fusion are drivers here

Maritime: Smart and un-crewed shipping

Defence: Military, homeland security, warfare, cyber-security

Space: Remote sensing, navigation in space, planetary navigation

Thank You.

SG41313 – Applications of GNSS

Year IV - Semester I

5- Applications of GNSS

MDEK Gunathilaka (PhD, MRICS)

DEPARTMENT OF SURVEYING AND GEODESY
FACULTY OF GEOMATICS

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1 Marine Applications…

1. To determine the position of a vessel and to navigate safely...

Eg: 1. Marine DGNSS Systems.

2. Vessel & Altitude Modeling.

- ✓ Far from Land.
- ✓ Line of Sight.
- ✓ 24h operation.
- ✓ No land mark.
- ✓ All weather conditions.

Dynamic Environment does not permit accurate positioning once floating as in Land surveying

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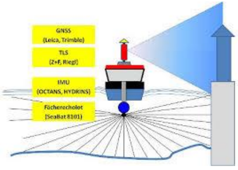
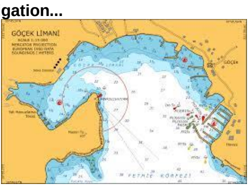
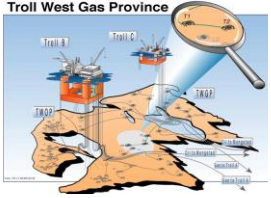
1. Positioning & Navigation...





2. Marine Engineering Applications...



Marine DGNSS Systems…?

1. RTK

Very Accurate (CM in all X,Y & Height) & Vessel Attitude measurements

Radio Units

Data formats: RTCM & NMEA

H and V Datum…(SLD99; MSL / LAT ?)

Good Geoid Model to get accurate heights…

About 5-10km range…, LoS,…

Power of the Radio 1W, 3W, 15W,…

Base

Rover

Marine DGNSS Systems…?

2. IALA Beacons

IALA

Less Accurate (<2m),
L1 code only

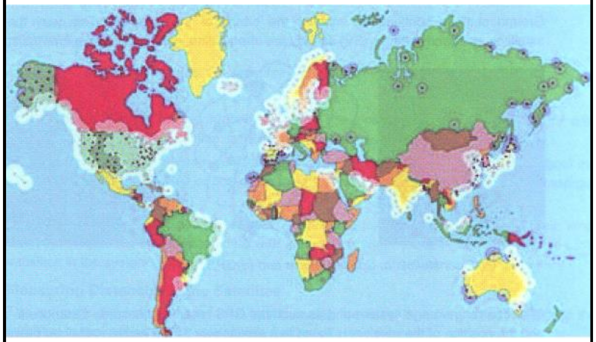
Free and available at all major ports…,

No global coverage.

NMEA

- ✓Established by IALA to ensure safe navigation in the waters.
- ✓IALAs ground-based reference station broadcast the differential corrections (L1).
- ✓Corrections are broadcasted using long wave radio (kHz) frequencies.
- ✓The GNSS antenna should be capable of receiving these radio signals.
- ✓Its free and each station having a unique ID.
- ✓About 2-3 meter accuracy over a longer distances (<300km) even with a single station.

World coverage of IALA beacons



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49 SINGAPORE

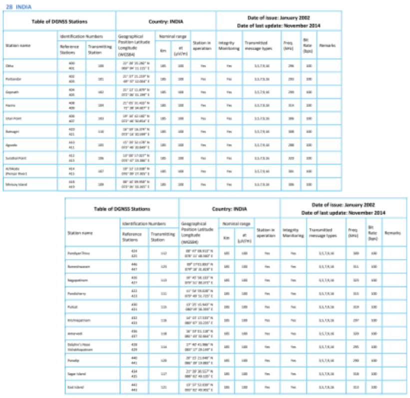
Table of DGNSS Stations			Country: SINGAPORE				Date of issue: January 2002 Date of last update: November 2014				
Station name	Identification Numbers		Geographical Position Latitude Longitude (WGS84)	Nominal range		Station in operation	Integrity Monitoring	Transmitted message types	Freq. (kHz)	Bit Rate (bps)	Remarks
	Reference Stations	Transmitting Station		Km	at (µV/m)						
PedraBranca (Horsburgh)	130 131	745	01° 19' N 104° 24' E	200	75	Yes	Yes	3 5 7 9 16	308	200	
PulauSatumu (Raffles)	132 133	746	01° 09' N 103° 44' E	200	75	Yes	Yes	3 5 7 9 16	298	200	

52 SRI LANKA

Table of DGNSS Stations			Country: SRI LANKA				Date of issue: January 2002 Date of last update: November 2014				
Station name	Identification Numbers		Geographical Position Latitude Longitude (WGS84)	Nominal range		Station in operation	Integrity Monitoring	Transmitted message types	Freq. (kHz)	Bit Rate (bps)	Remarks
	Reference Stations	Transmitting Station		Km	at (µV/m)						

Remarks:

1. No DGPS service currently



28 INDIA

Table of DGNSS Stations			Country: INDIA				Date of issue: January 2002 Date of last update: November 2014				
Station name	Identification Numbers		Geographical Position Latitude Longitude (WGS84)	Nominal range		Station in operation	Integrity Monitoring	Transmitted message types	Freq. (kHz)	Bit Rate (bps)	Remarks
	Reference Stations	Transmitting Station		Km	at (µV/m)						

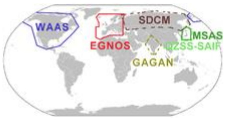
Table of DGNSS Stations			Country: INDIA				Date of issue: January 2002 Date of last update: November 2014				
Station name	Identification Numbers		Geographical Position Latitude Longitude (WGS84)	Nominal range		Station in operation	Integrity Monitoring	Transmitted message types	Freq. (kHz)	Bit Rate (bps)	Remarks
	Reference Stations	Transmitting Station		Km	at (µV/m)						

3. SBAS

✓**The network corrections are uplink to geo stationary satellites and broadcast over the region.**

✓**Provides improved location accuracy over an entire region…!**

✓**Starfix, OmniSTAR, Atlas, EGNOS, MSAS, etc**



Some systems transmit additional information about errors (clock drift, ephemeris, ionospheric delay, etc) >> more accurate >>> have to pay.

Tropo, Iono models weighted solution.

Class Assignment-1

1. **Draw a sketch and describe the hardware and data configuration in a ground based RTK positioning technique (radio RTK or NTRIP) for navigation.**

4.Marine DGNSS Systems…?

4. Commercial DGNSS Networks

Different Accuracies (Sub-M or DM),
L1/L2 code only
Weighted Solutions.
Error Modeling.

NMEA

Not Free any more, Global Coverage…

Eg. Omnistar, SeaStar, Atlas, etc

StarFix (FUGRO)

✓ **Positioning services with high accuracy worldwide.**

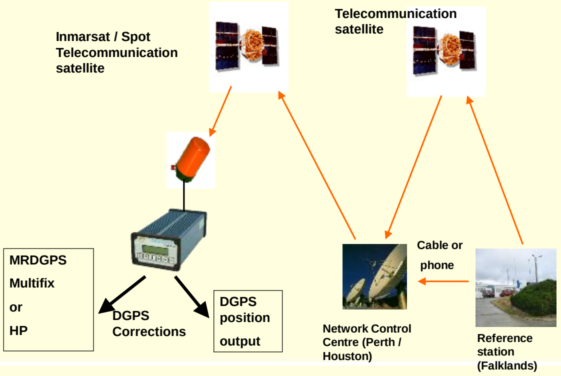
✓ **Full use of all available navigation satellite systems.**

✓ **Fugro's world-wide infrastructure for augmentation of existing Global Navigation systems (GNSS) with more than 100 reference stations dispersed on all continents, to measure and compare navigation satellite data.**

✓ **All correction services available on over 10 communication satellites for full redundant positioning coverage around the clock and around the globe.**

✓ **Longer Baselines > 500km.**

FUGRO StarFix Architecture



Inmarsat / Spot Telecommunication satellite

Telecommunication satellite

MRDGPS
Multifix
or
HP

DGPS Corrections

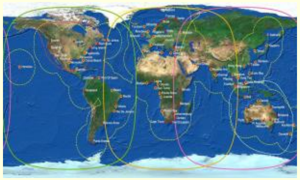
DGPS position output

Network Control Centre (Perth / Houston)

Cable or phone

Reference station (Falklands)

StarFix (FUGRO)



Not free anymore… have to subscribe

StarFix-Multiple Position Solutions

- **Starfix.L1**
  - This service utilises single frequency code correction data from the Fugro network of reference stations, delivered via L-Band satellite broadcasts.
  - These corrections, combined with a single frequency GNSS receiver are used to produce a position of high accuracy. This system can provide a positional accuracy of better than 1m (2σ) horizontally at a distance of 500 km from the nearest reference station.
- **MultiFix**
  - Single Station DGPS Position Computation.
  - Networked DGPS Position Computation.
  - Clock and Orbit Position Computation.
- **SPM 2000**
  - Single Station DGPS Position Computation.
  - Virtual Base/Reference Station (VBS/VRS) Position Computation.
  - Clock and Orbit Position Computation.

StarFix-Multiple Position Solutions

- **Starfix.XP2**
  - Starfix.XP2 service is a GPS and GLONASS positioning system that is based on orbit and clock corrections obtained from a third party supplier.
  - This utilises Carrier with Precise Point Positioning (PPP).
  - Further positional enhancements are undertaken in Fugro's software resulting in positional accuracies of better than 10cm and 20cm (2σ) in the horizontal and vertical planes respectively.

Refer more on FUGRO Starfix: *https://www.fugro.com/our-services/marine-asset-integrity/satellite-positioning/starfix*

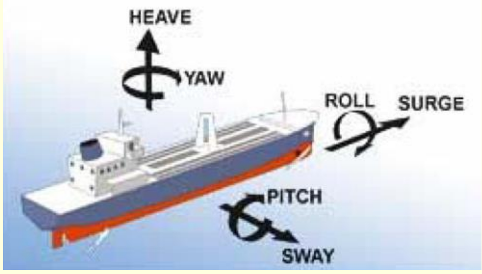
Type	Accuracy
Starfix.XHP Position	0.1m 2DRMS
Starfix.G2 Position	0.1m 2DRMS
Starfix.Plus Position	0.08m 2DRMS
GNSS Position	2.0m 2DRMS
Velocity	0.05m/s RMS

Refer more on ATLAS: https://www.hemispheregnss.com/product/atlas-gnss-global-correction-service/

Service Level – Position Accuracy
Atlas Basic – *50 cm 95% (30 cm RMS)*
Atlas H30 – *30 cm 95% (15 cm RMS)*
Atlas H10 – *8 cm 95% (4 cm RMS)*

Vessel Attitude Measurement…

To determine the movements of the vessel for various applications…(Navigation, Surveying, etc)



Attitude/Motion Measurements…

Conventionally- using Attitude Sensors;

- Heave Sensor – measure Heave
- Gyro Compass – Heading
- Motion Sensor (RPH) – Roll, Pitch, Heave



Using GNSS;

- Heave Sensor – RTK
- Gyro Compass – RTK, Two GNSS Antennae
- Motion Sensor (RPH) – Two GNSS Antennae + RTK

Moving Base GNSS

- ✓ Two GNSS antennae mounted in a fixed separation (fixed base line) and both are connected to a single unit.
- ✓ The errors are modeled reference to the known baseline length.
- ✓ Also can output heading and vessel motion data.
- ✓ Longer the base, accurate the data….
- ✓ Modern moving base receivers can receive other corrections (RTK/DGNSS) as well & accuracy is greatly increased.

Can externally create a moving base with two onboard GNSS units using the Hydrographic Software…

1-2 meter accuracy anywhere in the world, with out any base station….

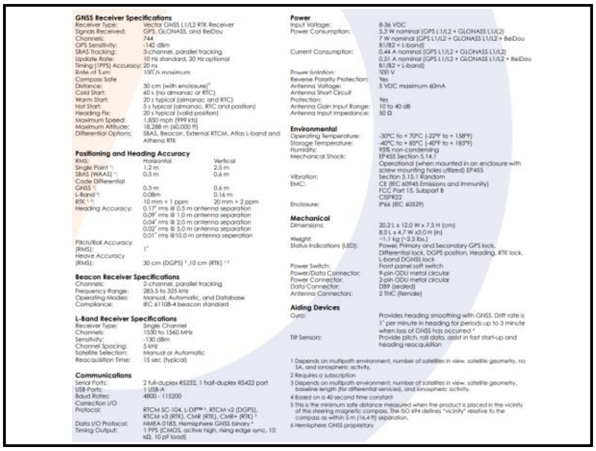
Vector™ VS330 GNSS Receiver

Professional Positioning and Heading Receiver

key features

- Athena™ RTK, Atlas™ L-band, Beacon and SBAS capable
- Extremely accurate heading with baselines up 50 m
- Multi-frequency GPS/GLONASS/BeiDou RTK capable
- Automatic antenna baseline survey
- Maintain heading and position lock when more of the sky is blocked
- Runs Athena core GNSS engine offering improved initialization times, robustness in difficult environments, performance over long baselines and under scintillation
- Integrated gyro and tilt sensors help deliver fast start-up times and provide heading updates during temporary loss of satellites

atlas



GNSS Receiver Specifications

Receiver Type:	Vector GNSS L1/L2 RTK Receiver
Signals Received:	GPS, GLONASS, and BeiDou
Channels:	744
GPS Sensitivity:	-142 dBm
SBAS Tracking:	3-channel, parallel tracking
Update Rate:	10 Hz standard, 20 Hz optional
Timing (1PPS) Accuracy:	20 ns
Rate of Turn:	100°/s maximum
Compass Safe Distance:	30 cm (with enclosure)[5]
Cold Start:	60 s (no almanac or RTC)
Warm Start:	20 s typical (almanac and RTC)
Hot Start:	5 s typical (almanac, RTC and position)
Heading Fix:	20 s typical (valid position)
Maximum Speed:	1,850 mph (999 kts)
Maximum Altitude:	18,288 m (60,000 ft)
Differential Options:	SBAS, Beacon, External RTCM, Atlas L-band and Athena RTK

Positioning and Heading Accuracy

RMS:	Horizontal	Vertical
Single Point [1]:	1.2 m	2.5 m
SBAS (WAAS) [1]:	0.3 m	0.6 m
Code Differential GNSS [1]:	0.3 m	0.6 m
L-Band [2]:	0.08m	0.16 m
RTK [1, 3]:	10 mm + 1 ppm	20 mm + 2 ppm
Heading Accuracy:	0.17° rms @ 0.5 m antenna separation 0.09° rms @ 1.0 m antenna separation 0.04° rms @ 2.0 m antenna separation 0.02° rms @ 5.0 m antenna separation 0.01° rms @10.0 m antenna seperation	
Pitch/Roll Accuracy (RMS):	1°	
Heave Accuracy (RMS):	30 cm (DGPS) [4], 10 cm (RTK) [1, 4]	

Beacon Receiver Specifications

Channels:	2-channel, parallel tracking
Frequency Range:	283.5 to 325 kHz
Operating Modes:	Manual, Automatic, and Database
Compliance:	IEC 61108-4 beacon standard

L-Band Receiver Specifications

Receiver Type:	Single Channel
Channels:	1530 to 1560 MHz
Sensitivity:	-130 dBm
Channel Spacing:	5 kHz
Satellite Selection:	Manual or Automatic
Reacquisition Time:	15 sec (typical)

Communications

Serial Ports:	2 full-duplex RS232, 1 half-duplex RS422 port
USB Ports:	1 USB-A
Baud Rates:	4800 - 115200
Correction I/O Protocol:	RTCM SC-104, L-Dif™ [6], RTCM v2 (DGPS), RTCM v3 (RTK), CMR (RTK), CMR+ (RTK) [3]
Data I/O Protocol:	NMEA 0183, Hemisphere GNSS binary [6]
Timing Output:	1 PPS (CMOS, active high, rising edge sync, 10 kΩ, 10 pF load)

Power

Input Voltage:	8-36 VDC
Power Consumption:	5.3 W nominal (GPS L1/L2 + GLONASS L1/L2) 7 W nominal (GPS L1/L2 + GLONASS L1/L2 + BeiDou B1/B2 + L-band)
Current Consumption:	0.44 A nominal (GPS L1/L2 + GLONASS L1/L2) 0.51 A nominal (GPS L1/L2 + GLONASS L1/L2 + BeiDou B1/B2 + L-band)
Power Isolation:	500 V
Reverse Polarity Protection:	Yes
Antenna Voltage:	5 VDC maximum 60mA
Antenna Short Circuit Protection:	Yes
Antenna Gain Input Range:	10 to 40 dB
Antenna Input Impedance:	50 Ω

Environmental

Operating Temperature:	-30°C to + 70°C (-22°F to + 158°F)
Storage Temperature:	-40°C to + 85°C (-40°F to + 185°F)
Humidity:	95% non-condensing
Mechanical Shock:	EP455 Section 5.14.1 Operational (when mounted in an enclosure with screw mounting holes utilized) EP455
Vibration:	Section 5.15.1 Random
EMC:	CE (IEC 60945 Emissions and Immunity) FCC Part 15, Subpart B CISPR22
Enclosure:	IP66 (IEC 60529)

Mechanical

Dimensions:	20.2 L x 12.0 W x 7.5 H (cm) 8.0 L x 4.7 W x3.0 H (in)
Weight:	~1.1 kg (~2.5 lbs.)
Status Indications (LED):	Power, Primary and Secondary GPS lock, Differential lock, DGPS position, Heading, RTK lock, L-band DGNSS lock
Power Switch:	Front panel soft switch
Power/Data Connector:	9-pin ODU metal circular
Power Connector:	2-pin ODU metal circular
Data Connector:	DB9 (sealed)
Antenna Connectors:	2 TNC (female)

Aiding Devices

Gyro:	Provides heading smoothing with GNSS. Drift rate is 1° per minute in heading for periods up to 3 minute when loss of GNSS has occurred [4]
Tilt Sensors:	Provide pitch, roll data, assist in fast start-up and heading reacquisition

[1] Depends on multipath environment, number of satellites in view, satellite geometry, no SA, and ionospheric activity.

[2] Requires a subscription

[3] Depends on multipath environment, number of satellites in view, satellite geometry, baseline length (for differential services), and ionospheric activity.

[4] Based on a 40 second time constant

[5] This is the minimum safe distance measured when the product is placed in the vicinity of the steering magnetic compass. The ISO 694 defines "vicinity" relative to the compass as within 5 m (16.4 ft) separation.

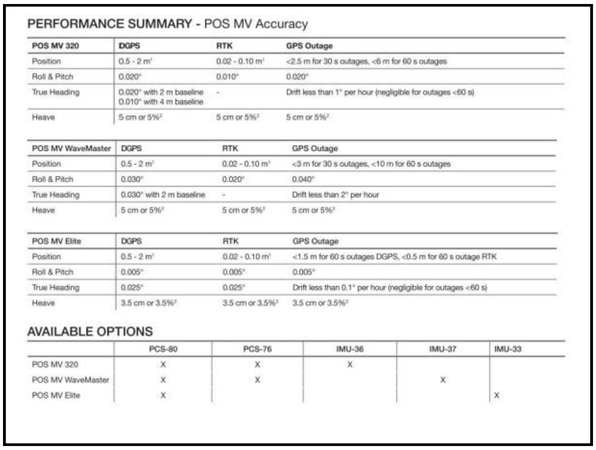
[6] Hemisphere GNSS proprietary

POS MV

- ✓ **POS MV blends GNSS data (moving base) with angular rate and acceleration data from an IMU.**
- ✓ **Produce a robust and accurate full six degrees of freedom Position and Orientation solution.**

cm accuracy anywhere in the world, with accurate vessel motion…

Accuracy has greatly increased with the Other GNSS corrections (SBAS, RTK, etc).



PERFORMANCE SUMMARY - POS MV Accuracy

POS MV 320	DGPS	RTK	GPS Outage
Position	0.5 - 2 m[1]	0.02 - 0.10 m[1]	<2.5 m for 30 s outages, <6 m for 60 s outages
Roll & Pitch	0.020°	0.010°	0.020°
True Heading	0.020° with 2 m baseline 0.010° with 4 m baseline	-	Drift less than 1° per hour (negligible for outages <60 s)
Heave	5 cm or 5%[2]	5 cm or 5%[2]	5 cm or 5%[2]

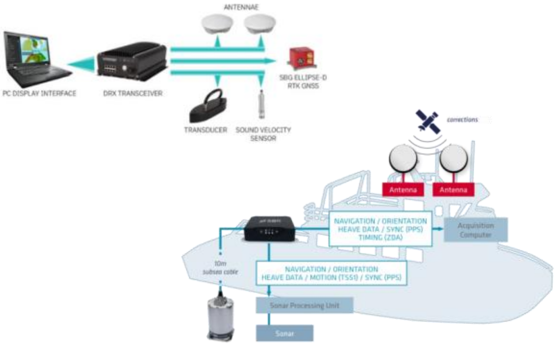
POS MV WaveMaster	DGPS	RTK	GPS Outage
Position	0.5 - 2 m[1]	0.02 - 0.10 m[1]	<3 m for 30 s outages, <10 m for 60 s outages
Roll & Pitch	0.030°	0.020°	0.040°
True Heading	0.030° with 2 m baseline	-	Drift less than 2° per hour
Heave	5 cm or 5%[2]	5 cm or 5%[2]	5 cm or 5%[2]

POS MV Elite	DGPS	RTK	GPS Outage
Position	0.5 - 2 m[1]	0.02 - 0.10 m[1]	<1.5 m for 60 s outages DGPS, <0.5 m for 60 s outage RTK
Roll & Pitch	0.005°	0.005°	0.005°
True Heading	0.025°	0.025°	Drift less than 0.1° per hour (negligible for outages <60 s)
Heave	3.5 cm or 3.5%[2]	3.5 cm or 3.5%[2]	3.5 cm or 3.5%[2]

AVAILABLE OPTIONS

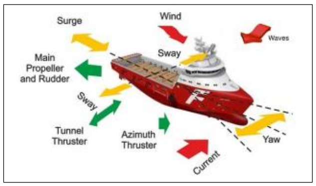
	PCS-80	PCS-76	IMU-36	IMU-37	IMU-33
POS MV 320	X	X	X		
POS MV WaveMaster	X	X		X	
POS MV Elite	X				X

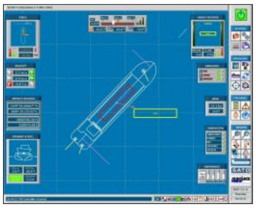
Eg. POS MV in Hydrography



Dynamic Positioning (DP)

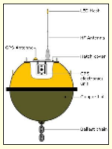
- ✓ A computer-controlled system to automatically maintain a vessel's position and heading by using its own propellers and thrusters.
- ✓ Intergraded with many sensors like GNSS, MRU, Gyro and sometimes the wind speed, current, etc.
- ✓ Important in some offshore applications in O&G industry.

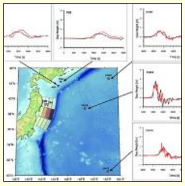




Other Marine Applications…

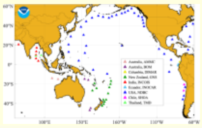
1. Meteorological : Cyclone tracking Buoys.

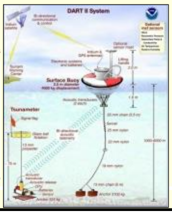




2. Tsunami Buoys…

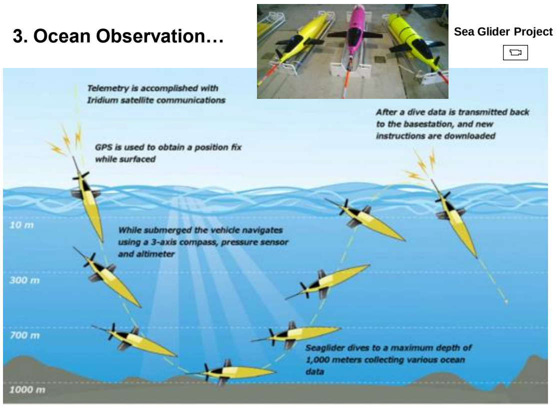
Deep-ocean Assessment and Reporting of Tsunamis





3. Ocean Observation…

Sea Glider Project



2 Vehicle Navigation…

1. To determine the vehicle location, tracking, navigation etc.

Driver less / Autonomous cars

2. To Determine the vehicle attitudes used for other sensors…

3. Aircraft Navigation.

Safe navigation and in taking off & landing…*Auto pilot…*

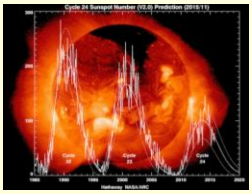
- **ILS – Instrument Landing System (https://www.youtube.com/playlist?list=PLthUARIELoUVcm0r6VTAobujwbaX9Jchs)**
- **GNSS**
- **WADGNSS - WASS**

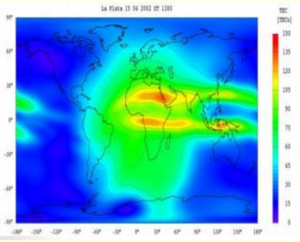
4. Space Craft Navigation.

- ✓ GNSS are originally designed for earth-based positioning and navigation.
- ✓ Also used in real-time spacecraft navigation such as low-Earth orbits and geostationary orbits, allowing satellites to self-determine their position using GNSS, reducing dependence on ground-based stations.

5. Space and weather Applications …

- Space Weather Modelling (GNSS metrology)
- Monitoring of Total Electron Content (TEC).





By GNSS network monitoring

Possible to relate with the phenomenon with the changes of the propagation errors eg: Cyclones, Droughts, etc…

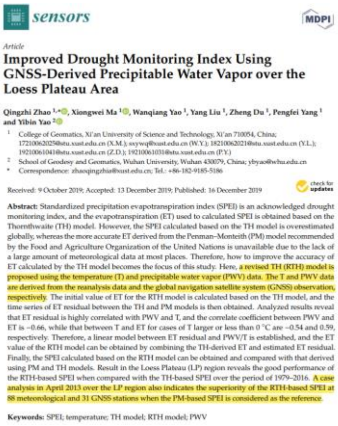
CA-2

'GNSS meteorology denotes the estimation of atmospheric parameters from GNSS observations and the subsequent use of those in meteorology'.

Find a suitable literature (a journal paper) on the above topic and make a summary by mentioning the objectives, methods used and the findings. Then, make a 10 min presentation in the class using the information from the same paper.

Group Assignment *(of 05 in a group)*

Eg. https://www.mdpi.com/597326



sensors MDPI

Article

Improved Drought Monitoring Index Using GNSS-Derived Precipitable Water Vapor over the Loess Plateau Area

Qingzhi Zhao [1,*], Xiongwei Ma [1], Wanqiang Yao [1], Yang Liu [1], Zheng Du [1], Pengfei Yang [1] and Yibin Yao [2]

[1] College of Geomatics, Xi'an University of Science and Technology, Xi'an 710054, China; 17210062025@stu.xust.edu.cn (X.M.); sxywq@xust.edu.cn (W.Y.); 18210062021@stu.xust.edu.cn (Y.L.); 19210061041@stu.xust.edu.cn (Z.D.); 19210061031@stu.xust.edu.cn (P.Y.)

[2] School of Geodesy and Geomatics, Wuhan University, Wuhan 430079, China; ybyao@whu.edu.cn

* Correspondence: zhaoqingzhia@xust.edu.cn; Tel.: +86-182-9185-5186

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check for updates

Abstract: Standardized precipitation evapotranspiration index (SPEI) is an acknowledged drought monitoring index, and the evapotranspiration (ET) used to calculated SPEI is obtained based on the Thornthwaite (TH) model. However, the SPEI calculated based on the TH model is overestimated globally, whereas the more accurate ET derived from the Penman–Monteith (PM) model recommended by the Food and Agriculture Organization of the United Nations is unavailable due to the lack of a large amount of meteorological data at most places. Therefore, how to improve the accuracy of ET calculated by the TH model becomes the focus of this study. Here, a revised TH (RTH) model is proposed using the temperature (T) and precipitable water vapor (PWV) data. The T and PWV data are derived from the reanalysis data and the global navigation satellite system (GNSS) observation, respectively. The initial value of ET for the RTH model is calculated based on the TH model, and the time series of ET residual between the TH and PM models is then obtained. Analyzed results reveal that ET residual is highly correlated with PWV and T, and the correlate coefficient between PWV and ET is −0.66, while that between T and ET for cases of T larger or less than 0 °C are −0.54 and 0.59, respectively. Therefore, a linear model between ET residual and PWV/T is established, and the ET value of the RTH model can be obtained by combining the TH-derived ET and estimated ET residual. Finally, the SPEI calculated based on the RTH model can be obtained and compared with that derived using PM and TH models. Result in the Loess Plateau (LP) region reveals the good performance of the RTH-based SPEI when compared with the TH-based SPEI over the period of 1979–2016. A case analysis in April 2013 over the LP region also indicates the superiority of the RTH-based SPEI at 88 meteorological and 31 GNSS stations when the PM-based SPEI is considered as the reference.

Keywords: SPEI; temperature; TH model; RTH model; PWV

---

6. Precise Timing…

- UTC (Coordinated Universal Time)
- GPS Time (Atomic clock, 01/01/1980)
- Leap seconds (as of Dec 2016, GPS18s ahead to UTC)
- Accurate Timing (money transactions)
- NMEA ZDA
- Time Synchronization (time tag data)

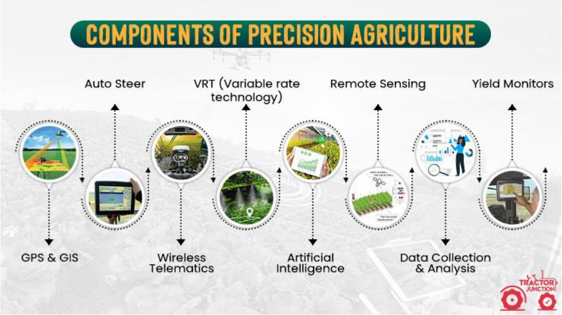
CA- 3 (Class Assignment)

Compare the advantages and disadvantages of the SBAS and GBAS?

Time- 15 minutes.

7. Miscellaneous - Engineering Applications & Machine Control Systems…

7. Miscellaneous - Precision Agriculture…

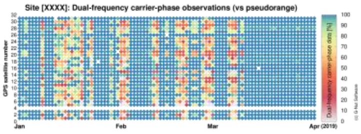


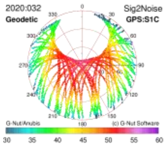
GNSS QA & QC…

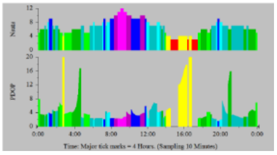
GNSS data QA & QC.

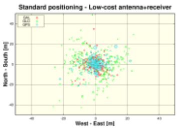
- ✓ Number of satellites
- ✓ DoP
- ✓ No of Known stations (single or networked)
- ✓ Error modeling
- ✓ Corrections
- ✓ Precautions (mask angle/ choke ring/ avoid obstacles)
- ✓ Data Processing methods (single/ networked /precise ephemeris, etc)
- ✓ Observation duration/ mode
- ✓ Statistical Analysis *(std, confidence level)*
- ✓ Validation

GNSS data QA & QC Plots.



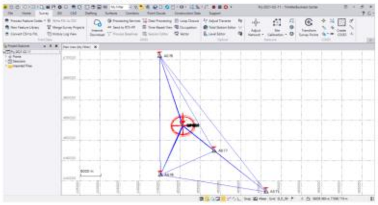






Network and Error Ellipse Analysis

Network Diagram on Trimble Business Center



Error Ellipse Components

Point ID	Semi-major axis (Meter)	Semi-minor axis (Meter)	Azimuth
D12	0.0086	0.0078	83°
D13	0.0083	0.0066	119°
D14	0.0087	0.0064	69°
D15	0.0117	0.0076	102°

Thank You.

Next – GNSS Future Developments...

SG41313 – Applications of GNSS

Year IV - Semester I

6- Future Trends/Developments in GNSS

MDEK Gunathilaka (PhD, MRICS)

DEPARTMENT OF SURVEYING AND GEODESY
FACULTY OF GEOMATICS

Future Trends/Developments…

Why:- For better accuracy and reliability…

Propagation error modelling: improved models.

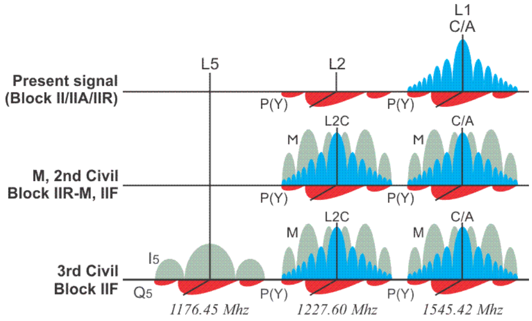
More and more local and regional GNSS networks.

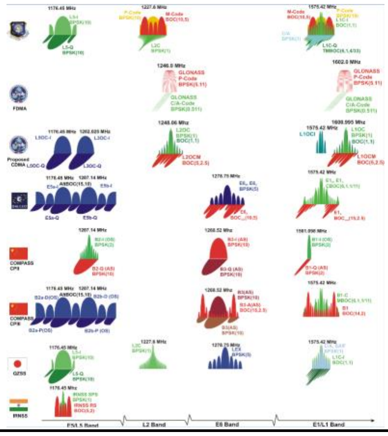
Multi-Frequency Combinations : L1, L2, LC, L5, P(Y), etc

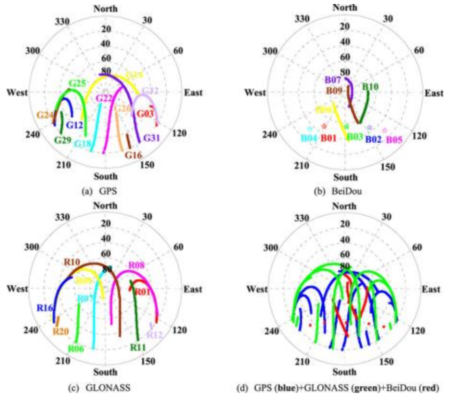
Multi-Constellation Measurements: GPS + GLONAS ++++

New & Improved Satellites : GPS III.

Applications with other Sensor Integration: GNSS + IMU + IPS







(a) GPS (b) BeiDou

(c) GLONASS (d) GPS (blue)+GLONASS (green)+BeiDou (red)

GPS IIR
- 13 satellites launched 1997-2004
- Design life: 7.5 years
- Status: 11 satellites still operational
- Frequencies: L1, L2
- Increased signal reliability
- Reprogrammable processors onboard

GPS IIR-M
- 8 satellites launched 2005-2009
- Design life: 7.5 years
- Status: 7 satellites still operational
- L2C Civilian signal added
- L1M and L2M Military signals added
- Anti-jam flex power

GPS IIF
- 12 satellites launched 2010–2016
- Design life: 12 years
- Status: 12 satellites still operational
- L5 safety-of-life signal added
- New M-code signal added
- Better resistance to jamming
- Reprogrammable processors can receive software uploads

GPS III
- 10 satellites under contract
- Design life of 15 years
- 3 times more accurate
- 8 times improved anti-jam capability
- L1C Global Navigation Satellite Systems (GNSS) compatibility
- Proven compatible with the current GPS constellation and the OCX ground control segment
- Evolves to incorporate new technology and changing mission needs

GPS IIIF
- 22 satellites under contract
- Search and Rescue, Laser Reflector Array and Digital Payload at SV 11+

CA- Make a comparison table of key improvements of the various GPS generations (blocks) over the history.

Open Book Assignment

- GPS Block II
- GPS Block IIF
- GPS Block III
- GPS Block IIIF

Thank You.

SG41313 – Applications of GNSS

Year IV - Semester I

7- Alternative PNT Technologies

MDEK Gunathilaka (PhD, MRICS)

DEPARTMENT OF SURVEYING AND GEODESY
FACULTY OF GEOMATICS

What is PNT…?

- Positioning - Determining the receiver/user coordinates.
- Navigation - Determining a route to a desired coordinate from the current coordinate.
- Timing - Determining time from a established time system (UTC).

Limitations in GNSS PNT…?

- Unintentional interference, like Radio Frequency Interference (RFI) or military trials and testing
- Low-power and unencrypted signals arriving on the earth - prone to unauthorized access
- Requires line of sight between receiver/user and satellite - GNSS denied environments
- Human factors, like errors, lack of knowledge or training

Real-world PNT Requirement…?

- To deliver GNSS-like performance anywhere, anytime, under any operating conditions.
- To exceed the performance levels of GNSS for safety and liability critical applications.
- GNSSs on their own cannot satisfy the “high-performance positioning” needs of applications that are either liability-critical or life-critical.

What is Alternative PNT…?

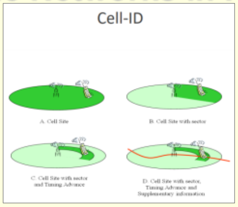
- Focus on enabling multisensory, low-cost and robust positioning solutions for a broad range of user applications, even in GNSS denied environments.
- Based on multiple users and different types of platforms and sensors (cooperative positioning).
- Assuring seamless transition between different sensors, platforms, approaches and environments - Plug-and-play concept.
- Goal: continuous and ubiquitous navigation solution in mixed environments.

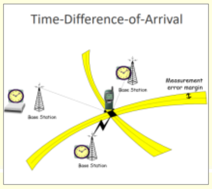
APNT…

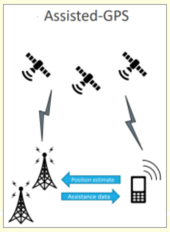
Cell Phone Networks in Positioning

- Cell phones and cell phone networks are globally distributed.
- For emergency calls and LBS.
- Positioning methods;
  - ✓ Cell-based positioning
  - ✓ Hyperbolic lateration
  - ✓ Assisted-GPS

Cell Phone Networks in Positioning



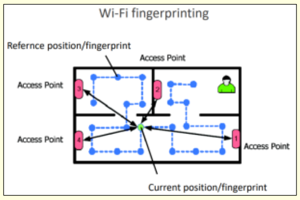


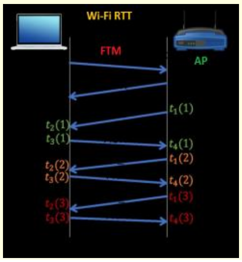


Wi-Fi Positioning…

- **Wi-Fi modules in mobile phones, laptops, smart watches, etc.**
- **Increasing number of public and private Access Points (APs)**
- **Attractive for Indoor and outdoor navigation, Pedestrian navigation in urban environments.**
- **Positioning techniques;**
  - ✓ Fingerprinting
  - ✓ Round-Trip-Time (RTT)

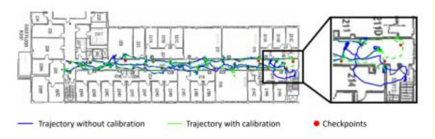
Wi-Fi Positioning…





UWB Positioning…

- **Operation in 3.1 to 10.6 GHz range**
- **Advantages regarding multipath and penetration**
- **Positioning methods:**
  - ✓ Fingerprinting
  - ✓ Geometric (Received signal strength indication -RSSI, Time of Arrival -ToA, Round Trip Time -RTT)
- **Calibration model to remove measurement bias**

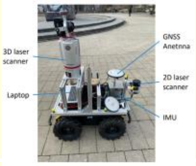


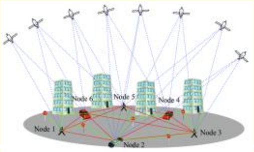
Vision-Aided Positioning…

- **Image-based localization**
- **Absolute and relative positioning**
- **Absolute positioning:** eg. database containing images of recognizable features in the surroundings with position information and matching with captured images and images in database leads to absolute position.
- **Relative Positioning:** eg. determination of the motion by observing a sequence of images of the environment, a database containing all previously captured images and matching of features between current and previous images leads to relative position…(SLAM?)

Sensor Fusion and Multi-Sensor positioning…

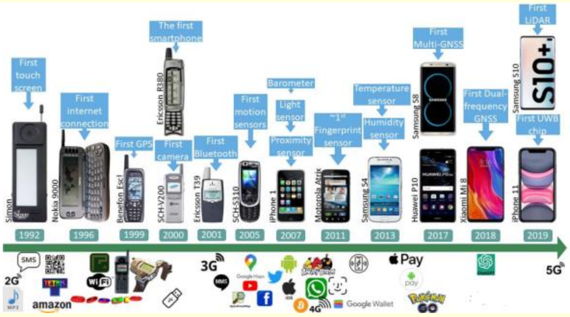
- **Combining positioning technique with other sensor data.**
- **Enhanced Navigation Solution.**
- **Primary sensors:** GNSS & IMU
- **Further sensors:** Radar, Lidar, camera, UWB, etc.
- **Fusion algorithmes:** Kalman filter, Artificiel intelligence.





Smart Phone Sensors

Evolution…



Smart Phone Sensors

Evolution…


Biometric sensor
GNSS
Ambient light sensor
Accelerometer
Proximity sensor
Gyroscope
Microphone
Magnetometer
LiDAR
Barometer
Camera
Wi-Fi
UWB
Bluetooth

Thank You.

Field Practical Task 01 – Applications of GNSS

BSc(Surveying Sciences)(Surveying & Geodesy)

Objectives;

- Establishing control network using GNSS techniques in the field.
- GNSS data processing (single base line and network processing).
- GNSS data QA & QC.

Methodology;

- Familiarize with the basic operational procedure of geodetic GNSS receivers for static (code) observations.
- Use 6-8 points inside the SUSL to establish a control network (having atlest 2 known station, following the DSR).
- Use one GNSS system as the Master and move the other GNSS units to the other stations as the Rowers. Change the rovers stations vies versa until all the baselines are observed.
- Starts observations simultaneously (at both stations) and one hour observation duration would be sufficient per baseline.
- Download the data and use both standard data formats and RINEX data processing (free and professional software).
  - i. Single base line processing.
  - ii. Network processing.
  - iii. Make a comparison of the results with statistics.
- Experiment with different data processing options as follows;
  - i. Changing the observation time and the accuracy (in single base line in 20 min span).
  - ii. Changing different constellation options (GPS only, GPS + GLONASS only, all combinations) and the accuracy (in single base line).
  - iii. Changing different frequency options (L1 only, L1 & L2 only and all possible combinations) and the accuracy (in single base line).
  - iv. With and without SBAS corrections (GAGAN) and the accuracy (in single base line).
  - v. PPS (IGS station data from Survey Department or Indian station)
  - vi. Short (50 km) and Long baseline (100-1000km) processing exercise with CORS and IGS stations.

Produce a comprehensive report on the complete task and submit before the deadline.

Two days for field work and 03 days of data processing & reporting is assigned for this task.

Field work and presentations will be a group one and data processing and reporting must be individual.

Supervisor: Dr. MDEK Gunathilaka

Field Practical Task 02 – Applications of GNSS

BSc(Surveying Sciences)(Surveying & Geodesy)

Objectives;

- Topographic and Road Survey using RTK GNSS technique.

Methodology;

- Familiarize with the basic field operational procedure of various GNSS techniques;
  i. Radio RTK
  ii. NTRIP(own base with GSM)
  iii. CORS (GSM & PPK/OTF)

- Use 5-10 known points within the university and compare the accuracy of each technique. *You may experiment with observation duration i.e. 10s, 20s, 1 min, 5 min etc.*
- Select an area (around the main playground about 4Ha) and do a detailed topographic survey and prepare a contour map (at 0.5m interval) of the area using Civil 3D).
- Select a road section (about 1km) and do a road survey using RTK (Radio/GSM or CORS) method and produce a Topo and LS/CS drawings using Civil 3D.

Produce a comprehensive report on the complete task and submit before the Deadline

Three days filed work and 02 days of data processing & reporting is assigned for the task.

Field work and presentations will be a group one and data processing, drawing and reporting must be individual.

Supervisor: Dr. MDEK Gunathilaka

Applications of GNSS – Practical Assignment -3 (group)

Demonstrate how to read an NMEA data string through a Serial/USB port coming from a GNSS unit. Try to show them how to extract the total number of satellites tracking from the NMEA data generate an output message from the computer as an example.

Then, let the students to work on the followings as a group.

G1 – Extract the time information (yyyy/mm/dd/hh/mm/ss.dddd) from the NMEA data and also output this timing data real-time through a serial port.

G2- Extract the position information (Lat & Long in DD/MM/SS.DDDD) from the NMEA data and also output this position data real-time through a serial port.

G3- Extract the ellipsoidal height information (mmm.DD) from the NMEA data and also output this height data real-time through a serial port.

G4- Estimate the heading information (dd/hh/ss/dddd, heading) from the NMEA data and also output this heading data real-time through a serial port.

G5- Extract the GNSS status information (dd/hh/ss/dddd, status) from the NMEA data and also output this status data real-time through a serial port.

G6- Extract the DoP value information (DD) from the NMEA data and also output this status data real-time through a serial port.

Also if possible, try to log this data as text file under each group for various application (eg. track the history of an animal with a radio+GNSS collar unit)