GPS

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Aman

GPS Survey

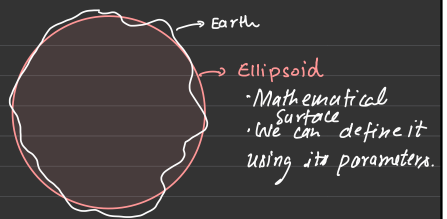
1. Reference ellipsoids and Coordinate Systems, GPS Principle, GPS Elements, applications of GPS, advantages and limitations.
2. GPS Errors, Differential GPS, and advantages.
3. GPS: Improving Accuracy, Various modes of Operation.

GPS: Global Positioning System

- GPS provides axis location.
  Where am I? Location
  Where is a particular object?
- GPS can help us to locate our position.
- Position is with reference to something so we need to define a coordinate system.
- GPS makes use of satellites. Using those satellites which are at a certain altitude we can know our position.

[Coordinate System]

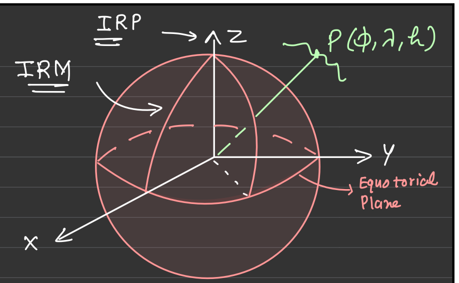
Reference Ellipsoid



- Mathematical surface
- Best fitting to earth
- Same mass and C.G. as of earth
- WGS-84 is one similar ellipsoid

- We fit an ellipsoid to earth because earth is slightly oblate. Oblate means it is not spherical, from the poles it is slightly pressed. On an undulating earth we are fitting an ellipsoid
- GPS make use of this WGS-84 ellipsoid for measuring the coordinates.

Geodetic Coordinate System (GCS)



(ϕ, λ, h)

φ → Latitude, λ → Longitude, h → Normal height

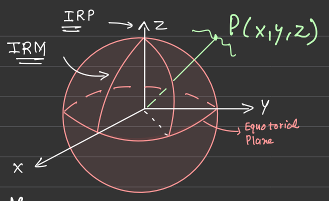
WGS-84

- IRP → IERS Reference Pole
  {International Earth Rotation Service}
- IRM → IERS Reference Meridian
- Right-handed Coordinate System

X → fixed → IRM
Z → fixed → IRP
Y → defined automatically because it is a right handed coordinate system.

Cartesian Coordinate System

(X, Y, Z)

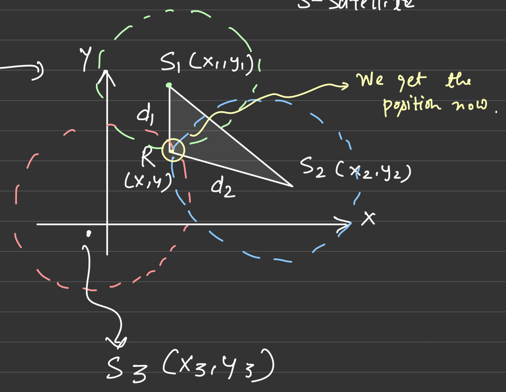


- $(\phi, \lambda, h) \Leftrightarrow (X, Y, Z)$
  We can determine one from the other.
- GPS will give us measurement in the WGS-84 Coordinate system with reference to this geocentric coordinate system either as (x, y, z) or (ϕ, λ, h)
- We can transform one from the other.
- In order to understand GPS, we should keep in our mind that yes there is a coordinate system sitting at the centre of earth. (mass centre of earth)

Principle of GPS

R - Receiver
S - Satellite

2D Example

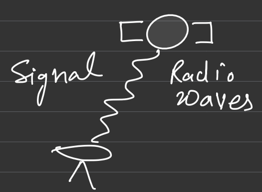


- GPS is 3-D
- 3 Satellites
  - Distance R-S = ?
  - Know where satellites are?

Distance of GPS Receiver from the Satellite:

$d = c \times t$ Satellites sending radio signals

How is 't' measured?
Accuracy in 't' important.



- S → R ✓ ⊙ ·R
  S
- R → S ✗

- How do we measure the distance?
  Synchronization of satellite and receiver is used.
  "same code at same time"

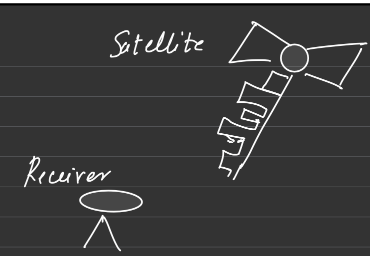
PRC

Pseudo Random Code

Radio waves : Carriers.

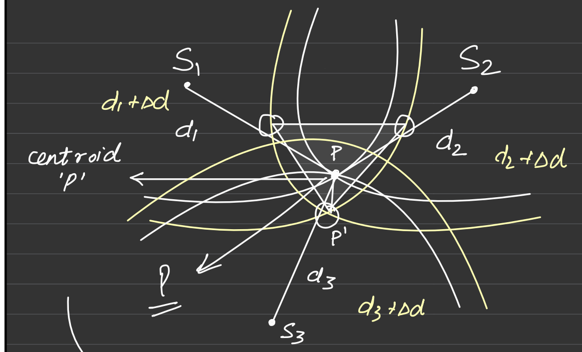
(1, 2, 3, 4, ...)

$t \times c = d$



- Time measurement accurately: 4th satellite
  Synchronisation error in receiver and satellite clock.

Clock Atomic (Satellite)
↳ Receiver
↳ Here clock is not atomic one and we want the receiver to be inexpensive so there is not proper synchronization.



2D

ⓓ

Δd – some error in distance

P P'

$S_1 - S_2 \rightarrow P'$

$S_1 - S_2 - S_3 \rightarrow$

3 satellites here can solve the problem for 2-D.
⟹ 4 satellite we need to have in 3-D problem.

- Centroid is the point 'P'
- Even if our receiver has synchronization error, still it is possible to determine the coordinate of the point accurately. The error's effect can be eliminated by measuring distances from 4 satellites in GPS.

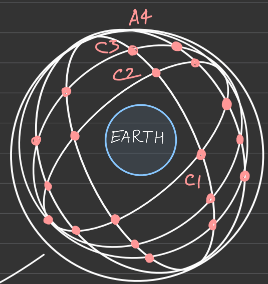
GPS which is mostly used around the world.

① NAVSTAR (U.S.A.)
Satellite Constellation : 1994 operational
24 satellites : At least 4 above horizon → visible (we recieve Signal)
Altitude : 20183 km

② Glonass (Russian)
③ Galileo (European Union)

- GPS is a generic term.
- 6 orbits with 4 satellites

A-F → 6 orbits
1–4 → satellites



NAVSTAR

They are positioned in such a way that at any time 't', we should be able to see 4 satellites.

Where are the Satellites?

- Satellites are put in stable orbits.
- DoD (Department of Defence) Monitoring
- "Ephemeris" transmitted to satellites.
- Navigation code with signal from satellites.

GPS Signal

⟹ L_1 Carrier – 1227.6 MHz
⟹ L_2 Carrier – 1575.42 MHz

Carrier

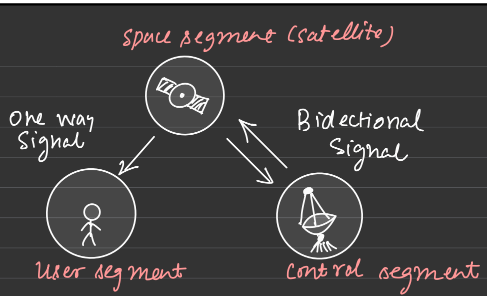
Ranging Code modulated on carriers.

↳ C/A code ⟹ (Clear Access) (Coarse Acquisition) → Not Precise
at 1.023 MHz → Civil

↳ P Code ⟹ (Private) (Protected) (Precise)
at 10.23 MHz → Military

GPS Segments

- Space
- Control
- User



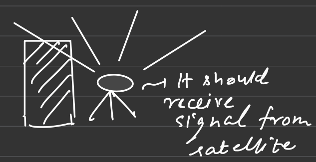
GPS
Geodetic
GS-5
PDA

Advantages of GPS

- Independent Positioning
- No intervisibility requirement
- Independent of Weather Conditions
- Survey Network (Control Points) as desired.
  - We'd to fix pts as to make a particular shape bcoz of angles. in GPS it isn't so.
- GPS Survey
  - ↳ Flexible
  - ↳ Accurate
  - ↳ Less time consuming
- Round-the-clock use
- Global 3D Coordinates

Limitations of GPS

- Expensive
- Cannot be used in: Underground, forest, urban area

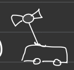


- Cannot be used in inaccessible areas.
  - ↳ For those areas, we use
    - LiDAR
    - Photogrammetry

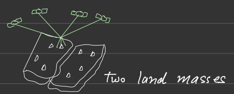
Applications of GPS:

"Wherever location is important"

- Mapping
- Vehicle Navigation (Intelligent Transport system)

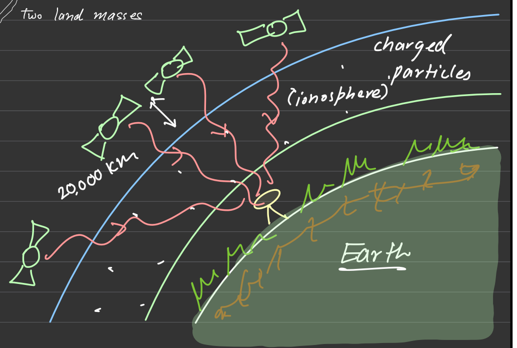


- Location Based Services (GIS + GPS + Mobile)
- Earthquake Prediction



Error in GPS Survey

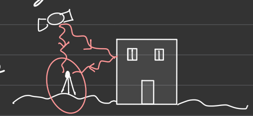
① Satellite Errors
- Atomic Clock
- Orbit Errors



② The atmosphere
- Slowing speed of signal
- Unpredictable variation of atmosphere
- Correction by average atmosphere

Ionospheric-free solution — Dual Frequency $L_1 - L_2$
↳ By observing relative slowing of L_1 & L_2.

③ Multipath Error



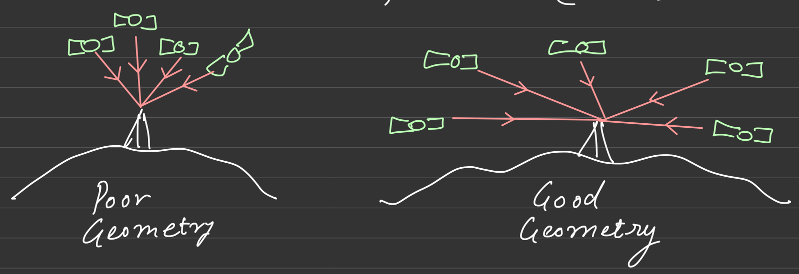
④ Receive Error
- Clock
- Internal Noise

⑤ Intentionally Introduced Errors
- Corrupting Satellite Clock with noise
- Corruption in Navigation Data

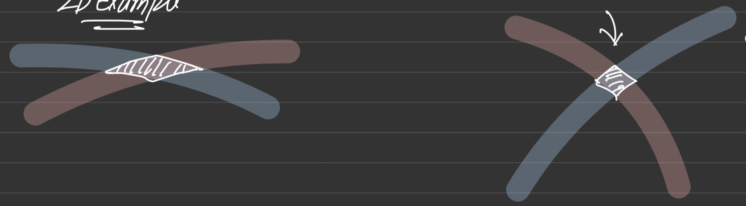
(Selective Availability) DoD

⑥ Geometry of Visible Satellites

↳ Geometric Dilution of Precision (GDoP)



2D Example



When angle is about 90°, the area of uncertainty is less.

⇒ GDoP is a measure of geometry of satellites
⇒ A scalar

Effect of GDoP

User equivalent range error (UERE) — σ_r

↳ Measure of accuracy of single pseudo range measurement.

$\sigma^* = GDoP \times \sigma_r$

σ^* S.D. of positions

- Smaller GDoP better   GDoP < 5 is considered good.

GPS Services

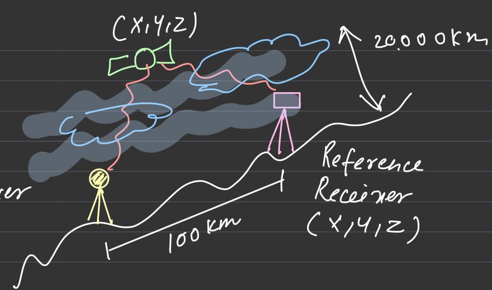
— SPS (Standard Positioning service) — Based on Single L_1 - C/A Code] Civilian Users

— PPS (Precise Positioning service) — Based on Dual frequency — P Code] Military U.S.

Accuracy achievable by single G.P.S. (code phase)

	SPS: With SA	SPS: Now without SA	PPS
Positioning Accuracy	± 50m	± 10m	±5m

Differential GPS (DGPS)



- Error due to ionosphere and troposphere are same.
- both receivers are making use of same satellites
  → error due to clock is same.

① Actual Time Computation

$[(X,Y,Z)_S , (X,Y,Z)_R] = d_{SR}$

$t_a - d_{SR}$

Measured time - t_m

Error in time $t_a - t_m = \Delta t$

Δt computed for all satellites

- Corrections will keep changing.
- Simultaneous observation needed for entire period of survey.

Processing of data :-

- Post processing of data
- Real time processing of data
  - Error due to latency.

Beacons as reference receivers ?

↳ Transmitting corrections in their local area.

Example :- WAAS (Wide Area Augmentation Service)
↳ since 1991
↳ on portable GPS 2001

- Some errors can be eliminated by the Differential GPS.
- Error because of the receiver or because of the multipath can not be eliminated by differential positioning because that is a local error.
- Only errors because of atmosphere or because of the satellite can be eliminated.

GPS Measurement Tecniques

③

① Code phase based ranging
② Carrier phase based ranging ⟶ More accurate

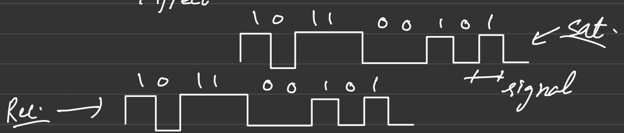
Code based measurement

→ Pseudo random code correlation 't'
→ Pseudo range determination
→ 4 pseudo ranges needed
↳ Location of the receiver

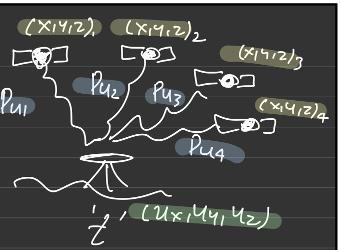
- C/A code ⟶ 1.023 MHz → 2.93 m
- P code ⟶ 10.23 MHz → 29.3 m → ?

↳ Effect

Accuracy of P code is more than C/A code.



Computation of Receiver Location



(x,y,z) — Location of i^{th} sat

P_u^i — Pseudo ranges from receiver 'u' to satellite 'i'

dT_u — Receiver clock error

I $\quad P_u^1 = \sqrt{(x_1-x_u)^2+(y_1-y_u)^2+(z_1-z_u)^2} = cdT_u$

II $\quad P_u^2 = \sqrt{(x_2-x_u)^2+(y_2-y_u)^2+(z_2-z_u)^2} = cdT_u$

III $\quad P_u^3 = \sqrt{(x_3-x_u)^2+(y_3-y_u)^2+(z_3-z_u)^2} = cdT_u$

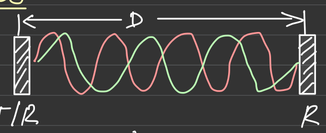
IV $\quad P_u^4 = \sqrt{(x_4-x_u)^2+(y_4-y_u)^2+(z_4-z_u)^2} = cdT_u$

$\Rightarrow$ Solving provides (u_x, u_y, u_z) → Location of the receiver

Carrier phase based measurement

Decade Modulation

EDMI



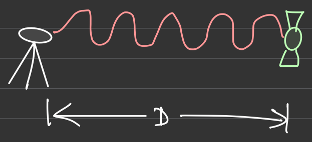
$$D = \frac{1}{2}\left(N\lambda + \frac{\Delta\phi}{2\pi}\lambda\right)$$

λ wavelength
$\Delta\phi$ phase
N

↳ Active ranging system

GPS Passive Ranging System
↳

$$D = N\lambda + \frac{\Delta\phi}{2\pi}\lambda$$



$\Delta\phi$ = Difference between received carrier phase and phase of the Quartz Crystal Oscillator in receiver.

$$D = N\lambda + \frac{\Delta\phi}{2\pi}\lambda + \text{errors}$$

- $\Delta\phi$ → measured with high accuracy 3-10 mm

[⇒ In C/A ≈ 1MHz
⇒ carrier ≈ 1000 MHz]

Implication?

C/A ~ 1MHz → 300 m
Carrier ~ 1000 MHz → 0.30 m

by $c = \nu\lambda$

$$D = N\cdot\lambda + \frac{\Delta\phi}{2\pi}\lambda$$

$\partial D \propto \lambda$
$\propto \delta\Delta\phi$

smaller
↓
more accurate position]//

- N → How to know N? Full cycles

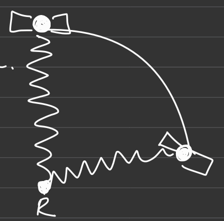
Resolving Carrier phase ambiguity ⇒ N
or Integer ambiguity

Ambiguity resolution ⇒ Value of N.

Various algorithms are available [Locking]

General Steps:-

→ Need prior value of ambiguity parameters
  ↳ Known reference point
  ↳ Use of code based pseudo range
→ Use of dual frequency and best geometry of satellite.
→ After locking $\Delta\phi$ is measured continuously.
→ N remains same for full direction of observation.
→ Additional cycles are counted.
Extra Cycles



Comparison

1. Code phase based ranging
   ↳ Simple, Fast, No need of initial value
   ↳ Less accurate : 300m
2. Carrier phase based ranging
   ↳ More accurate
   ↳ Complex, Time consuming, Initial Value.

Types of GPS Receivers

1. Code phase Receiver
   - Use P or C/A code
   - less accurate
   - Fast

   GIS data updation 1:50,000

2. Carrier phase Receiver
   ↳ Use carrier frequency
   1. Single frequency
      - L_1
      - Cheaper - Ionospheric Error
   2. Dual frequency → Costly
      - L_1 and L_2
      - Eliminates Ionospheric Error

▷ Classification based on data use
- C/A
- C/A + L_1 carrier
- C/A + L_1 carrier + L_2 carrier
- C/A + P + L_1 + L_2

▷ Classification based on channel

- Multi channel : 8, 12, 24 → can simultaneously lock with many satellites simultaneously.
- Sequential Receiver → one by one
  - ⇓ Time consuming
  - ↳ Less accurate
  - ↳ Cheaper

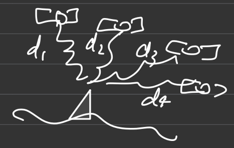
▷ Integrated GPS receiver

NAVSTAR + GLONASS
↑ ↑

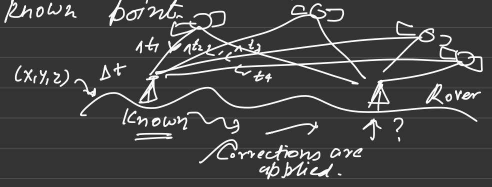
GPS Positioning Approaches

1. Point vs. Relative
2. Static vs. Kinematic
3. Real time vs. Post mission

Point Positioning :
↳ Single Point Positioning
↳ Absolute Positioning



Relative Positioning:
↳ Coordinates of an unknown point with respect to receiver at a known point.



Static : GPS receiver static
Kinematic : GPS receiver moving

Real time positioning : (Real time computation of position)

Single point :
Relative :
→ Latency
→ Use of broadcast ephemeris.

Post mission positioning :-

Single point :
Relative :
(Use of precise ephemeris) → available from website.

Nominal Positioning Accuracies in DGPS

GPS Receiver	Estimated Accuracy 95% Code	Carrier
① Low Cost	3-5 m	n/a ✗
② Geodetic Quality L4 channels L_1-L_2, static	0.3-1 m	2mm ± 1ppm
③ RTK with Geodetic receiver (Carrier)	n/a ✗	10-50mm

Best accuracy ↘ (2mm ± 1ppm)
Post processing
Instrument
baseline distance