THE NAVIC STANDARD

Through Python

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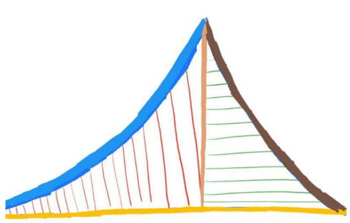

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Introduction

This book introduces the NAVIC communication standard through Python exercises

Chapter 1

Design Parameters

1.1. The Frequency Bands

Chapter 2

Channel Modelling

The phenomena modelled in the satellite communication channel are Doppler shift, delay, power scaling and receiver noise.

2.1. Doppler shift

Due to relative motion between the satellites and the receiver, the transmitted signals undergo a frequency shift before arriving at the receiver. This shiftin frequency is called Doppler shift and can be computed as

$$f_{shift} = f_d - f_c = \left(\frac{V_{rel}}{c - V_{S,dir}} \right) f_c \tag{2.1}$$

where,

f_{Shift} = Frequency shift due to Doppler

f_d = Frequency observed at receiver

f_c = Carrier frequency at transmitter

V_{rel} = Relative velocity of transmitter and receiver

$V_{S,dir}$ = Velocity of satellite along radial direction

c = Speed of light

V_{rel} is given by

$$V_{rel} = V_{S,dir} - V_{R,dir} \tag{2.2}$$

where,

$V_{R,dir}$ = Velocity of receiver along radial direction

$V_{R,dir}$ and $V_{S,dir}$ are given by

$$V_{R,dir} = \mathbf{V}_R \cdot \hat{\mathbf{dir}} \tag{2.3}$$

$$V_{D,dir} = \mathbf{V}_S \cdot \hat{\mathbf{dir}} \tag{2.4}$$

where,

$\hat{\mathbf{dir}}$ = Unit vector from satellite to receiver i.e. radial direction

$\mathbf{V_S}$ = Velocity of satellite

$\mathbf{V_R}$ = Velocity of receiver

$\hat{\mathbf{dir}}$ is given by

$$\hat{\mathbf{dir}} = \frac{\mathbf{P_S} - \mathbf{P_R}}{\|\mathbf{P_S} - \mathbf{P_R}\|} \tag{2.5}$$

where,

$\mathbf{P_S}$ = Position of satellite

$\mathbf{P_R}$ = Position of receiver

The Doppler shift is introduced by muliplying the satellite signal with a complex exponential,

$$x_{Shift}[n] = x[n]\, e^{-2\pi j (f_c + f_{Shift}) n t_s} \tag{2.6}$$

where,

$x_{Shift}[n]$ = Doppler shifted signal

$x[n]$ = Satellite signal

t_s = Sampling period

2.2. Delay

Since there is a finite distance between the satellite and the receiver, the signal at the reciever is a delayed version of the transmitted signal. This delay is given by

$$D_s = \frac{d}{c} f_s \tag{2.7}$$

where,

D_s = Total delay in samples

d = Distance between satellite and receiver

c = Speed of light

f_s = Sampling rate

The total delay on the satellite signal is modeled in two steps. First, a static delay is modeled which does not change with time and it is always an integer number of samples. Then, a variable delay is modeled which can be a rational number of samples. While modelling the static delay, the entire delay is not introduced so that variable delay modelling handles the remaining delay.

To introduce the static delay, the samples are read from a queue whose size is the desired static delay length. When samples are read from the queue, an equal number of new samples are updated in the queue. To introduce the variable delay, the signal is passed through an all-pass FIR filter with an almost constant phase response. Its coefficients are calculated using the delay value required.

2.3. Power Scaling

When a transmitting antenna transmits radio waves to a receiving antenna, the radio wave power received is given by,

$$P_r = P_t D_t D_r \left(\frac{1}{4\pi \left(f_c + f_{Shift} \right) D} \right)^2 \tag{2.8}$$

where,

P_r = Received power

P_t = Transmitted power

D_t = Directivity of transmitting antenna

D_r = Directivity of receiving antenna

D = Total delay in seconds

To scale the received signal as per the received power calculated,

$$x_{Scaled}\left[n\right] = \frac{\sqrt{P_r}}{\mathrm{rms}\left(x\left[n\right]\right)} x\left[n\right] \tag{2.9}$$

2.4. Receiver noise

Chapter 3

Transmitter

3.1. Frame structure

NavIC master frame consists of 2400 symbols, divided to four subframes. Each subframe is 600 symbols long. Subframes 1 and 2 transmit fixed navigation parameters. Subframe 3 and 4 transmit secondary navigation parameters in the form of messages. Each subframe is 292 bits long without FEC encoding and sync word. It starts with TLM word of 8 bits. Ends with 24 bit Cyclic Redundancy Check(CRC) followed by 6 tail bits. In subframes 1 and 2 navigation data is alloted 232 bits, starting from bit 31. In subframe 3 and 4, 220 bits are alloted starting from bit 37. For detailed structure of subframes, refer to chapter 5.9 in the doc

3.1.1. Cyclic Redundancy Check(CRC)

The parity coding of data signal follows 24Q polynomial for each subframe. 24 bits of CRC parity will provide protection against burst as well as random errors with undetected eroor probability of 2^{-24} for all channel bit error probabilities 0.5

$$g(X) = \sum_{i=0}^{24} g_i X^i \quad g_i = 1 \; for \; i = 0, 1, 3, 4, 5, 6, 7, 10, 11, 14, 17, 18, 23, 24 \tag{3.1}$$

3.2. Encoding

The navigation data subframe of 292 bits is rate 1/2 convolution encoded and clocked at 50 symbols per second. Each subframe of 292 bits after encoding results in 584 bits. For parameters and coding scheme, refer to below doc

3.2.1. Interleaving

Any burst errors during the data transmission can be corrected by interleaving. In matrix interleaving, input symbols are filled into a matrix column wise and read at the output row wise. This will spread the burst error, if any, during the transmission. For SPS, data is filled into matrix of size 73 by 8(73 columns, 8 rows).

3.2.2. Sync word and Tail bits

Each subframe has a 16 bit word synchronization pattern which is not encoded. Sync pattern is EB90 Hex. Tail bit consists of 6 zero value bits enabling completion of FEC decoding of each subframe in the receiver.

3.3. Modulation

3.3.1. Standard Positioning Service

The SPS signal is BPSK(1) modulated on L5 and S bands. The navigation data at data rate of 50 sps (1/2 rate FEC encoded) is modulo 2 added to PRN code chipped at 1.023 Mcps. The CDMA modulated code, modulates the L5 and S carriers at 1176.45 MHz and 2492.028 MHz respectively.

3.3.2. Pseudo Random Noise codes(PRN)

NavIC uses Gold codes fo SPS signal. They are generated using Linear Feedback Shift Registers. For L5 and S band, the code length is 1ms and consists of 1023 chips. The code is chipped at 1.023 Mcps. Two polynomials G1 and G2 are used to generate the gold code sequence. G2's initial state provides unique PRN code for each satellite. All bits of G1 are initialized as 1. G1 and G2 are XOR'ed to generate final 1023 chip long PRN sequence, the time period being 1ms. For more information refer to chapter 4 in the doc.

3.3.3. Baseband Modulation

The carrier signal is modulated by BPSK(1), Data channel BOC(5,2), and Pilot Channel BOC(5,2). To have a constant envelop when passed through power amplifier, we add additional signal called interplex signal. For detailed mathematical equations, refer to chapter 3.3 in the below document

Chapter 4

Computing the Position and Velocity of the satellite from the RINEX file

4.1. Introduction

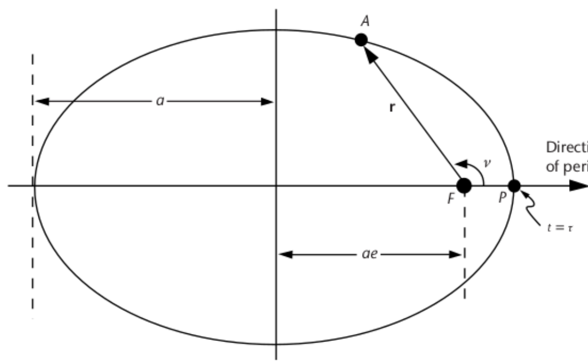
In order to achieve the navigation services we have to find the position and velocity of satellite in its orbit.In order to find the position and velocity we have the source called RINEX file Which contains all the orbital parameters of the satellite in its orbit.In this document we compute the position and velocity of GPS and NAVIC satellites.The RINEX files is different for both the satellites but the algorithm for finding the position and velocity is same.

4.2. Determination of satellite position

RINEX files will be available in official websites for all the satellites.The RINEX files contains all the information of the orbital parameters of the particular satellite.The Orbital elements of satellite from rinex file is given in below table.

4.2.1. Orbital parameters in rinex file

$\sqrt{a}$	Square rooot of semimajor axis
e	Eccentricity
Δn	Mean motion diffeerence from computed value
M_0	Mean anom maly at reference time
Ω_0	Longitude of ascending node n of orbit plane at weekly epoch
i_0	Inclination angle a at reference time
w	Argum ment of perigee
$\Omega_.$	Rate of right ascension
IDOT	Rate off inclination angle
t_{oe}	Ephemeeris reference time
IODE	Issue of data, ephemeris
C_{uc}	Amplitude of cosine harmonic h correction term to the argum ment of latitude
C_{us}	Amplitude of sine harmonnic correction term to the argument of latitude
C_{rc}	Amplitude of cosine harrmonic correction term to the orbit radius
C_{rs}	Amplitude of sine harm monic correction term to the orbit radius
C_{ic}	Amplitude of cosine harm monic correction term to the angle of i inclination
C_{is}	Amplitude of sine harmoonic correction term to the angle of i inclination



In the above Figure

1. The elliptical orbit has a focus at point F, which corresponds to the center of the mass of the Earth.

2. The time t0 at which the satellite is at some reference point A in its orbit is known as the epoch.

3. The point, P, where the satellite is closest to the center of the Earth is known as perigee.

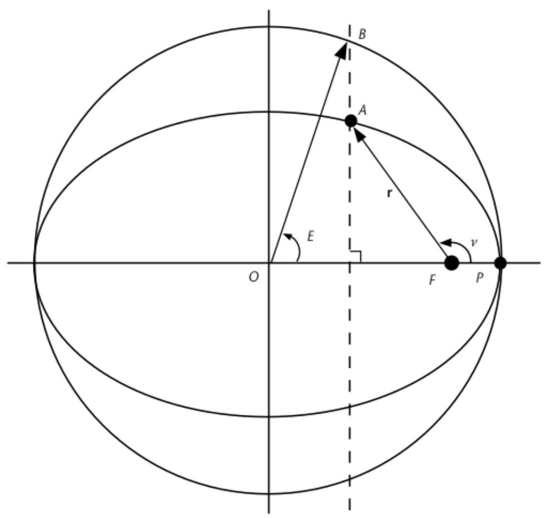
4. The time at which the satellite passes perigee,t, is another Keplerian orbital parameter.

The three Keplerian orbital elements that define the shape of the elliptical orbit and time relative to perigee are as follows:

1. a = Semimajor axis of the ellipse

2. e = eccentricity of the ellipse

3. t = time of perigee passage



In order to find the position of satellite let us understand the keplerian orbital elements.

True anamoly : The angle in the orbital plane measured counterclockwise from the direction of perigee to the satellite.

Eccentric anamoly : Geometrically, the eccentric anomaly is constructed from the true anomaly first by circumscribing a circle around the elliptical orbit. Next, a perpendicular is dropped from the point A on the orbit to the major axis of the orbit, and this per- pendicular is extended upward until it intersects the circumscribed circle at point B. The angle measured at the center of the circle, O, counter- clockwise from the direction of perigee to the line segment.

$$E = 2\arctan\left(\sqrt{\frac{1+e}{1-e}}\tan\left(\frac{v}{2}\right)\right) \tag{4.1}$$

Mean anamoly : The importance of transforming from the true to the mean anomaly is that time varies linearly with the mean anomaly.

$$M = M_o + n * (t - t_o) \tag{4.2}$$

Where,

M_o is Mean anamoly at the time of epch.

M is the mean anomaly at time t.

$$n = \sqrt{\frac{\mu}{a^3}} \tag{4.3}$$

$$\mu = 398,600.5 * 10^8 m^3/s^2 \tag{4.4}$$

In the case of GPS or Navic, the Keplerian parameters are defined in relation to the ECEF coordinate system .In this case, the xy-plane is always the Earth's equatorial plane. The following three Keplerian orbital elements define the orientation of the orbit in the ECEF coordinate system:

Inclination of orbit : Inclination is the dihedral angle between the Earth's equatorial plane and the satellite's orbital plane.

longitude of the ascending node : The orbital element that defines the angle between the +x-axis and the direction of the ascending node is called the right ascension of the ascending node (RAAN). Because the +x-axis is fixed in the direc- tion of the prime meridian (0° longitude) in the ECEF coordinate system, the right ascension of the ascending node is actually the longitude of the ascending node,Ω.

Arguement of perigee : Measures the angle from the ascending node to the direction of perigee in the orbit.

Notice that Ω is measured in the equatorial plane, whereas ω is measured in the orbital plane. The following formulas are used for computing the position,velocity of the satellite in the elliptical orbit.Where the inputs are taken from the rinex file.

$$\Omega^{\cdot} = 7.2921151467 * 10^{-5} rad/sec \tag{4.5}$$

$$a = \sqrt{a^2} \tag{4.6}$$

$$t_k = t - t_o e \tag{4.7}$$

$$n = n_o + \Delta n \tag{4.8}$$

$$M_k = M_o + n t_k \tag{4.9}$$

$$E_k = M_k + e \sin(E_k) \tag{4.10}$$

$$\sin(v_k) = \frac{1 - e^2 sin E_k}{1 - ecos E_k} \tag{4.11}$$

$$\cos(v_k) = \frac{\cos(E_K) - e}{1 - ecos(E_k)} \tag{4.12}$$

$$\phi_k = v_k + w \tag{4.13}$$

$$\delta\phi_k = C_{us} \sin(2\phi_k) + C_{uc} \cos(2\phi_k k) \tag{4.14}$$

$$\delta r_k = C_{rs} \sin(2\phi_k) + C_{rc} \cos(2\phi_k) \tag{4.15}$$

$$\delta i_k = C_{is} \sin(2\phi_k) + C_{ic} \cos(2\phi_k) \tag{4.16}$$

$$u_k = \phi_k + \delta\phi_k \tag{4.17}$$

$$r_k = a(1 - e \cos E_k) + \delta r_k \tag{4.18}$$

$$i_k = i_0 + \frac{di}{dt} t_k + \delta i_k \tag{4.19}$$

$$\Omega_k = \Omega_0 + \Omega^{\cdot} - \Omega^{\cdot}_e(t_k) - \Omega^{\cdot}_e t_{oe} \tag{4.20}$$

$$x_p = r_k \cos(u_k) \tag{4.21}$$

$$y_p = r_k \sin(u_k) \tag{4.22}$$

$$x_s = x_p \cos\Omega_k - y_p \cos i_k \sin\Omega_k \tag{4.23}$$

$$y_s = x_p \sin\Omega_k - y_p \cos i_k \cos\Omega_k \tag{4.24}$$

$$z_s = y_p \sin i_k \tag{4.25}$$

By computing the above formulas $[x_s, y_s, z_s]$ are the position of satellite in ECEF cooedinate frame. The velocity of the satellite is obtained by differentiating the above position equations with respect to time.The final equation is as follows:

$x_v = -x_p \dot{\Omega_k} \sin \Omega_k + \dot{x_p} \cos \Omega_k - \dot{y_p} \sin \Omega_k \cos i_k$
$-y_p(\dot{\Omega_k} \cos \Omega_k \cos i_k - \frac{dik}{dt} \sin \Omega_k \sin i_k)$

$y_v = -x_p \dot{\Omega_k} \cos \Omega_k + \dot{x_p} \sin \Omega_k - \dot{y_p} \cos \Omega_k \cos i_k$
$-y_p(\dot{\Omega_k} \sin \Omega_k \cos i_k - \frac{dik}{dt} \cos \Omega_k \sin i_k)$

$z_v = y_p \frac{di_k}{dt} \cos i_k + \dot{y_p} \sin i_k$

By computing the above formulas $[x_v, y_v, z_v]$ is the velocity vector of satellite in ECEF coordinate frame.

Computations of error corrections :

1. **Clock Correction :**

   One of the largest sources of error in calculating range is satellite clock error. To get the accuracy of the receiver position signal transmission and reception time must be precisely known. Because of the travel time of light, one nanosecond of inaccuracy in the clock causes 30 centimeter error in position. Satellite clock correction coefficients - clock bias, clock drift, and clock drift rate are obtained from the RINEX Navigation file. Calculation of the satellite clock error is given by

   $$\Delta t_{clk} = a_{f0} + a_{f1}(t - t_{oc}) + a_{f2}(t - t_{oc})^2 \tag{4.26}$$

   where ,

   Δt_{clk} is clock offset in seconds.

t is IRNSS system time at transmission in seconds.

t_{oc} is clock data reference time.

a_{f0} is clock bias.

a_{f1} is clock drift.

a_{f2} is clock drift rate.

2. **Relativistic Correction :**

   Because of the high speed of satellites and weaker gravity, clocks on the satellites run a little faster than the clock on the Earth. Error found because the relativity is in nanoseconds. The computation of relativistic clock error is given by

   $$\delta_{rel} = Fe\sqrt{a}\sin(E) \tag{4.27}$$

   where ,

   a is semimajor axis of the ellipse.

   e is eccentricity of the ellipse.

   F is -4.442807633 * 10^{-10}

   E is Eccentric anamoly. δ_{rel} is relativistic clock correction

4.3. Computing the position and velocity of the GPS satellite using python

Installations :

1. pip3 install pymap3d

2. pip3 install georinex

3. pip3 install itertools

4. pip3 install argparse

Algorithm for finding the position and velocity of satellite From Rinex file :

1. Get the rinex file for GPS satellite from the official website.

2. The Rinex file contains the observational file and navigation file.

3. Convert the Rinex file to CSV file using the python

   The below python function will convert the GPS RINEX file to CSV file.

   ```
   ./rinex_to_csv/funcs.py
   ```

4. Remove the empty rows in csv file.The python function for removing empty rows is

   ```
   ./rinex_to_csv/funcs.py
   ```

5. Convert the csv file to list in python so that each row is corresponds to the parameters of the satellite. Function for converting the csv file to list is given as :

   ```
   ./rinexread/funcs.py
   ```

6. Process the above list with the formulas mentioned in chaprter 2

   The python function for finding the position of satellite is given as :

   ```
   ./position/funcs.py
   ```

7. The velocity of the satellte is computed by the function

   ```
   ./velocity/funcs.py
   ```

8. The distance between the satellite and receiver is obtained by the python package called **pymap3d**,using this package convert ECEF to spherical coordinate frame.So that we obtain the distance between satellite and receiver.

9. These position and velocity of the satellite is used for computing the doppler shift.

The above alogorith will work for both GPS and Navic sarellite.If there is a problem in converting Navic RINEX file to csv file then follow the instructions below:

1. go to the mentioned folder in your laptop.

```
./home/mannava/.local/lib/python3.10/site−packages/georinex/nav3.py
```

2. Go to the line 220 in nav3.py file and modify the below changes.

```
elif numval == 29: # only one trailing spare fields
        cf = cf[:−2]
    elif numval == 28: # only one trailing spare fields
        cf = cf[:−3]
    elif numval == 27: # only one trailing spare fields
        cf = cf[:−4]
    elif numval == 26: # only one trailing spare fields
        cf = cf[:−5]
```