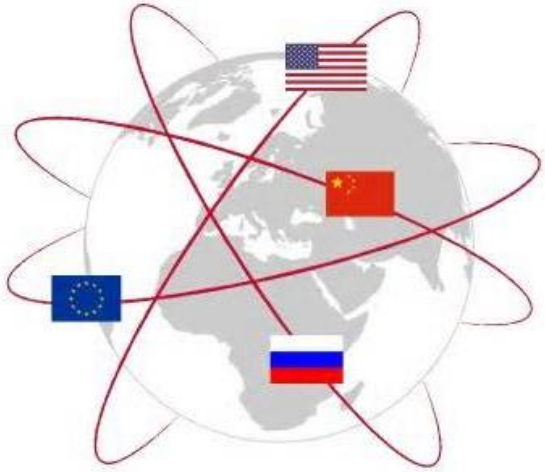

GNSS 测量原理与应用

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2020 春

第三章 卫星运动理论及星历

3.1 卫星轨道概述
3.2 卫星的无摄运动
3.3 卫星的受摄运动
3.4卫星轨道确定
3.5 卫星星历

第三章 卫星运动理论及星历

1.卫星轨道[illegible]

2.卫星[illegible]

3.卫星的受[illegible]

4.卫星轨道确定

3.5 卫星星历

GPS卫星星历

- 卫星星历是描述卫星运动轨道的信息，是一组对应某一时刻的轨道根数及其变率。
- 根据卫星星历可以计算出某一时间段内任一时刻的卫星位置及其速度。

GPS卫星星历分为

- 预报星历（广播星历）
- 后处理星历（精密星历）sp3格式。
- 广播星历实时更新，精密星历需要10几天才能更新。

IGS Product Table [GPS Broadcast values included for comparison]

		Accuracy	Latency	Updates	Sample Interval
GPS Satellite Ephemerides/ Satellite & Station Clocks					
Broadcast	orbits	~100 cm	real time	--	daily
	Sat. clocks	~5 ns RMS ~2.5 ns SDev			
Ultra-Rapid (predicted half)	orbits	~5 cm	real time	at 03, 09, 15, 21 UTC	15 min
	Sat. clocks	~3 ns RMS ~1.5 ns SDev			
Ultra-Rapid (observed half)	orbits	~3 cm	3 - 9 hours	at 03, 09, 15, 21 UTC	15 min
	Sat. clocks	~150 ps RMS ~50 ps SDev			
Rapid	orbits	~2.5 cm	17 - 41 hours	at 17 UTC daily	15 min
	Sat. & Stn. clocks	~75 ps RMS ~25 ps SDev			5 min
Final	orbits	~2.5 cm	12 - 18 days	every Thursday	15 min
	Sat. & Stn. clocks	~75 ps RMS ~20 ps SDev			Sat.: 30s Stn.: 5 min

- Final： available at 12 days latency.
- Rapid： available with approximately 17 hours latency.
- UltraRapid： released four times each day (at 0300, 0900, 1500, and 2100 UT) and contain 48 hours worth of orbits;
- the first half computed from observations and the second half predicted orbit.
- The files are named according to the midpoint time in the file: 00, 06, 12, and 18 UT.

GPS卫星星历

➢卫星星历参数共16个，其中包括1个参考时刻，6个相应参考时刻的开普勒轨道参数和9个反映摄动力影响的参数。

t_{0e}——参考历元

6个轨道参数：

M_{s0}——参考时刻的平近点角

e_s——轨道偏心率

$a_s^{1/2}$——轨道长半径的平方根

Ω_0——参考时刻的升交点赤经

i_0——参考时刻的轨道倾角

ω_s——近地点角距

导航电文中的参数

9个摄动力修正项

- $\dot{\Omega}$ ——升交点赤经变化率
- i ——轨道倾角变化率
- Δn ——由精密星历计算得到的卫星平均角速度与按给定参数计算所得的平均角速度之差。
- C_{uc}，C_{us}——升交距角的余弦、正弦调和改正项振幅
- C_{rc}，C_{rs} ——卫星地心距的余弦、正弦调和改正项振幅
- C_{ic}，C_{is} ——轨道倾角的余弦正弦调和改正项振幅

AODE——星历数据的龄期（外推星历的外推时间间隔）

a_0——卫星钟差

a_1——卫星钟速（频率偏差系数）

a_2——卫星钟速变化率（漂移系数）

RINEX格式导航文件示例

```
     2                NAVIGATION DATA                         RINEX VERSION / TYPE
ASHTORIN             CRG                 26 - JAN - 95 09:32 PGM / RUN BY / DATE
                                                             ! COMMENT
                                                             END OF HEADER
 4 94  7 12 20  0  0.0 .342605635524D-04 .159161572810D-11 .000000000000D+00
      .600000000000D+02 -.667500000000D+02  .487127433670D-08  .303566113163D+01
     -.326149165630D-05  .307378894649D-02  .384263694286D-05  .515358797455D+04
      .244800000000D+06  .596046447754D-07  .261429824751D+01  .596046447754D-07
      .963849281906D+00  .306562500000D+03 -.123948803468D+01 -.839856411962D-08
     -.195008122871D-09  .000000000000D+00  .757000000000D+03  .000000000000D+00
      .700000000000D+01  .000000000000D+00  .139698386192D-08  .572000000000D+03
      .237600000000D+06  .000000000000D+00  .000000000000D+00  .000000000000D+00
 5 94  7 12 20  0  0.0 .503696501255D-04 .193267624127D-11 .000000000000D+00
      .700000000000D+02 -.162500000000D+01  .432482300338D-08 -.148006722862D+01
     -.122934579849D-06  .211503100581D-02  .109970569611D-04  .515357275772D+04
      .244800000000D+06  .558793544769D-07  .498066950099D+00 -.484287738800D-07
      .956390825220D+00  .161718750000D+03 -.233509409274D+01 -.795211695188D-08
     -.233938315898D-09  .000000000000D+00  .757000000000D+03  .000000000000D+00
      .700000000000D+01  .000000000000D+00  .139698386192D-08  .326000000000D+03
      .237600000000D+06  .000000000000D+00  .000000000000D+00  .000000000000D+00
 7 94  7 12 18 51 44.0 .696869101375D-03 .227373675443D-12 .000000000000D+00
      .204000000000D+03  .799375000000D+02  .468662378812D-08 -.108349326313D+01
      .421330332756D-05  .638657843228D-02  .624358654022D-05  .515375518036D+04
      .240704000000D+06  .108033418655D-06  .154828270074D+01  .875443220139D-07
      .962376723196D+00  .260218750000D+03 -.270905310022D+01 -.835891961113D-08
      .416803075807D-09  .000000000000D+00  .757000000000D+03  .000000000000D+00
      .700000000000D+01  .000000000000D+00  .139698386192D-08  .204000000000D+03
      .237600000000D+06  .000000000000D+00  .000000000000D+00  .000000000000D+00
18 94  7 12 20  0  0.0 -.112131237984D-05 -.227373675443D-12 .000000000000D+00
      .156000000000D+03  .637812500000D+02  .514878589617D-08 -.633624380107D+00
      .327639281750D-05  .553935009521D-02  .806525349617D-05  .515375880623D+04
      .244800000000D+06 -.167638063431D-07 -.160860961533D+01  .113621354103D-06
      .942848673020D+00  .216062500000D+03  .132629925977D+01 -.845035199108D-08
```

a_0 a_1 a_2

TABLE A3

GPS NAVIGATION MESSAGE FILE - HEADER SECTION DESCRIPTION

	HEADER LABEL (Columns 61-80)	DESCRIPTION	FORMAT
	RINEX VERSION / TYPE	- Format version (2.10) - File type ('N' for Navigation data)	F9.2,11X, A1,19X
	PGM / RUN BY / DATE	- Name of program creating current file - Name of agency creating current file - Date of file creation	A20, A20, A20
*	COMMENT	Comment line(s)	A60
*	ION ALPHA	Ionosphere parameters A0-A3 of almanac (page 18 of subframe 4)	2X,4D12.4
*	ION BETA	Ionosphere parameters B0-B3 of almanac	2X,4D12.4
*	DELTA-UTC: A0,A1,T,W	Almanac parameters to compute time in UTC (page 18 of subframe 4) A0,A1: terms of polynomial T : reference time for UTC data W : UTC reference week number. Continuous number, not mod(1024)!	3X,2D19.12, 2I9 *)
*	LEAP SECONDS	Delta time due to leap seconds	I6
	END OF HEADER	Last record in the header section.	60X

Records marked with * are optional

TABLE A4

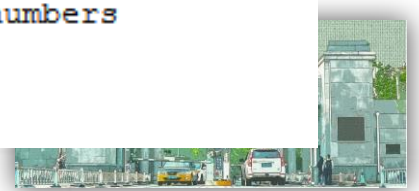
GPS NAVIGATION MESSAGE FILE - DATA RECORD DESCRIPTION

OBS. RECORD	DESCRIPTION		FORMAT
PRN / EPOCH / SV CLK	- Satellite PRN number		I2,
	- Epoch: Toc - Time of Clock		
	year (2 digits, padded with 0 if necessary)		1X,I2.2,
	month		1X,I2,
	day		1X,I2,
	hour		1X,I2,
	minute		1X,I2,
	second		F5.1,
	- SV clock bias	(seconds)	3D19.12
	- SV clock drift	(sec/sec)	
	- SV clock drift rate	(sec/sec2)	*)
BROADCAST ORBIT - 1	- IODE Issue of Data, Ephemeris		3X,4D19.12
	- Crs	(meters)	
	- Delta n	(radians/sec)	
	- M0	(radians)	
BROADCAST ORBIT - 2	- Cuc	(radians)	3X,4D19.12
	- e Eccentricity		
	- Cus	(radians)	
	- sqrt(A)	(sqrt(m))	
BROADCAST ORBIT - 3	- Toe Time of Ephemeris		3X,4D19.12
		(sec of GPS week)	
	- Cic	(radians)	
	- OMEGA	(radians)	
	- CIS	(radians)	
BROADCAST ORBIT - 4	- i0	(radians)	3X,4D19.12
	- Crc	(meters)	
	- omega	(radians)	
	- OMEGA DOT	(radians/sec)	

BROADCAST ORBIT - 4	- i0 (radians) - Crc (meters) - omega (radians) - OMEGA DOT (radians/sec)	3X,4D19.12
BROADCAST ORBIT - 5	- IDOT (radians/sec) - Codes on L2 channel - GPS Week # (to go with TOE) Continuous number, not mod(1024)! - L2 P data flag	3X,4D19.12
BROADCAST ORBIT - 6	- SV accuracy (meters) - SV health (bits 17-22 w 3 sf 1) - TGD (seconds) - IODC Issue of Data, Clock	3X,4D19.12
BROADCAST ORBIT - 7	- Transmission time of message **) (sec of GPS week, derived e.g. from Z-count in Hand Over Word (HOW) - Fit interval (hours) (see ICD-GPS-200, 20.3.4.4) Zero if not known - spare - spare	3X,4D19.12

**) Adjust the Transmission time of message by -604800 to refer to the reported week, if necessary.

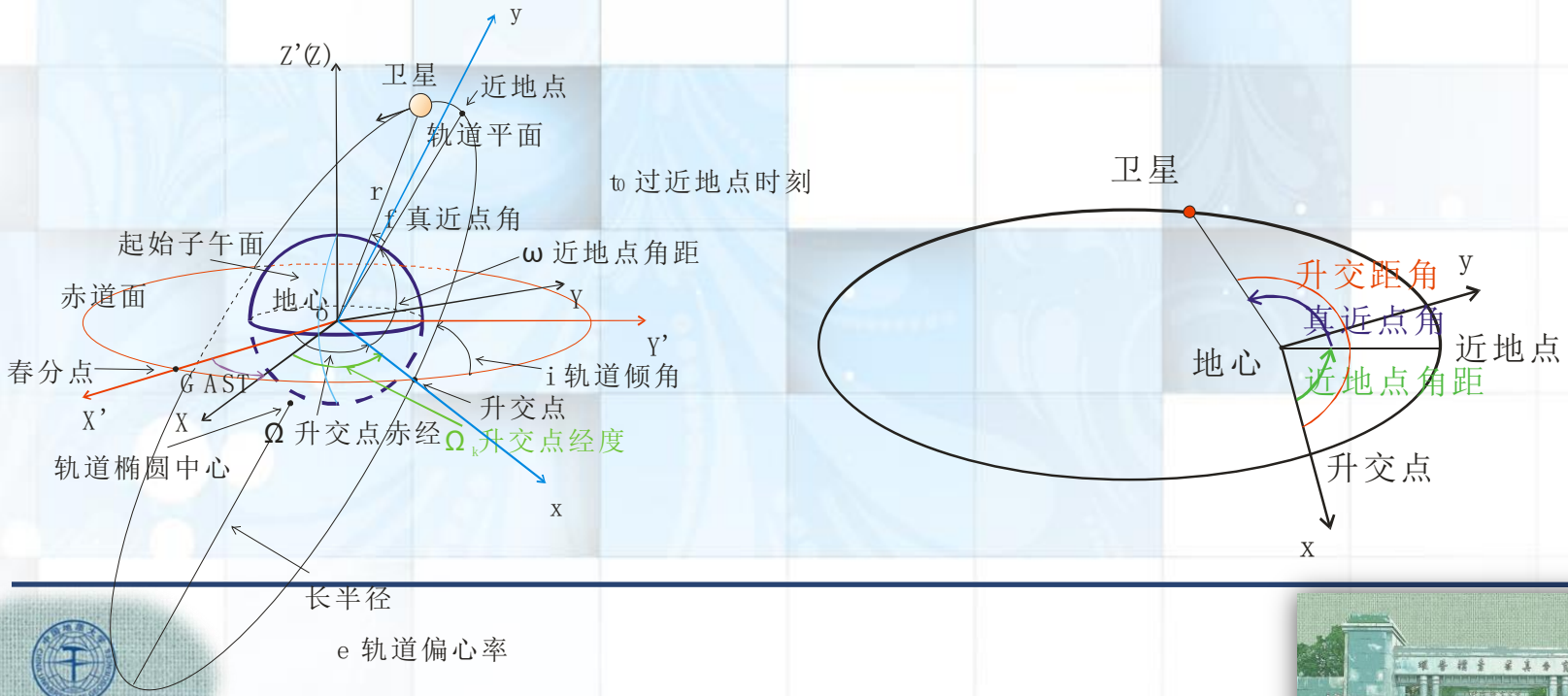
*) In order to account for the various compilers, E,e,D, and d are allowed letters between the fraction and exponent of all floating point numbers in the navigation message files.
Zero-padded two-digit exponents are required, however.



- ftp://ftp.unibe.ch/aiub/rinex/rinex211.txt

根据广播星历计算卫星位置

- 计算思路
  - ✓首先计算卫星在轨道平面坐标系下的坐标
  - ✓然后将上述坐标分别绕*X*轴旋转-*i*角、绕*Z*轴旋转-Ω_k角，求出卫星在地固系下的坐标



- 计算卫星运行的平均角速度

$$n_0 = \sqrt{\frac{GM}{a^3}} = \frac{\sqrt{\mu}}{(\sqrt{a})^3}$$

μ称为地球引力常数，在$WGS84$系中定义为$3.986005\times10^{14}\ m^3/s^2$

$$n = n_0 + \Delta n$$

- 计算t时刻卫星的平近点角

$$M(t) = M_0 + n\cdot(t - t_{oe})$$

- 计算偏近点角

$$E(t) = M(t) + e\cdot\sin E(t)$$

- 计算真近点角

$$f(t) = arctg\left(\frac{\sqrt{1-e^2}\sin E(t)}{\cos E(t) - e}\right)$$

- 计算升交距角（未经改正的）

$$u'(t) = \omega + f(t)$$

- 计算卫星向径

$$r'(t) = A(1 - e \cdot \cos E(t))$$

- 计算摄动改正项

$$\delta u(t) = C_{uc} \cdot \cos(2u'(t)) + C_{us} \cdot \sin(2u'(t))$$

$$\delta r(t) = C_{rc} \cdot \cos(2u'(t)) + C_{rs} \cdot \sin(2u'(t))$$

$$\delta i(t) = C_{ic} \cdot \cos(2u'(t)) + C_{is} \cdot \sin(2u'(t))$$

- 进行摄动改正

$$u(t) = u'(t) + \delta u(t)$$

$$r(t) = r'(t) + \delta r(t)$$

$$i(t) = i_0 + \dot{i} \cdot (t - t_{oe}) + \delta i(t)$$

- 计算卫星在轨道平面坐标系中的位置

$$x(t) = r(t) \cdot \cos u(t)$$

$$y(t) = r(t) \cdot \sin u(t)$$

- 计算升交点经度

$$\Omega_k(t) = \Omega_0 + (\dot{\Omega} - \omega_e)\cdot(t - t_{oe}) - \omega_e \cdot t_{oe}$$

- 计算卫星在地固坐标系下的坐标

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = R_Z(-\Omega_k(t))R_x(-i(t))\begin{pmatrix} x \\ y \\ 0 \end{pmatrix} = \begin{pmatrix} x\cdot\cos\Omega_k(t) - y\cdot\cos i(t)\cdot\sin\Omega_k(t) \\ x\cdot\sin\Omega_k(t) - y\cdot\cos i(t)\cdot\cos\Omega_k(t) \\ y\cdot\sin\Omega_k(t) \end{pmatrix}$$

总 结

- GPS卫星运动规律
- GPS星历