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卫星轨道确定方法

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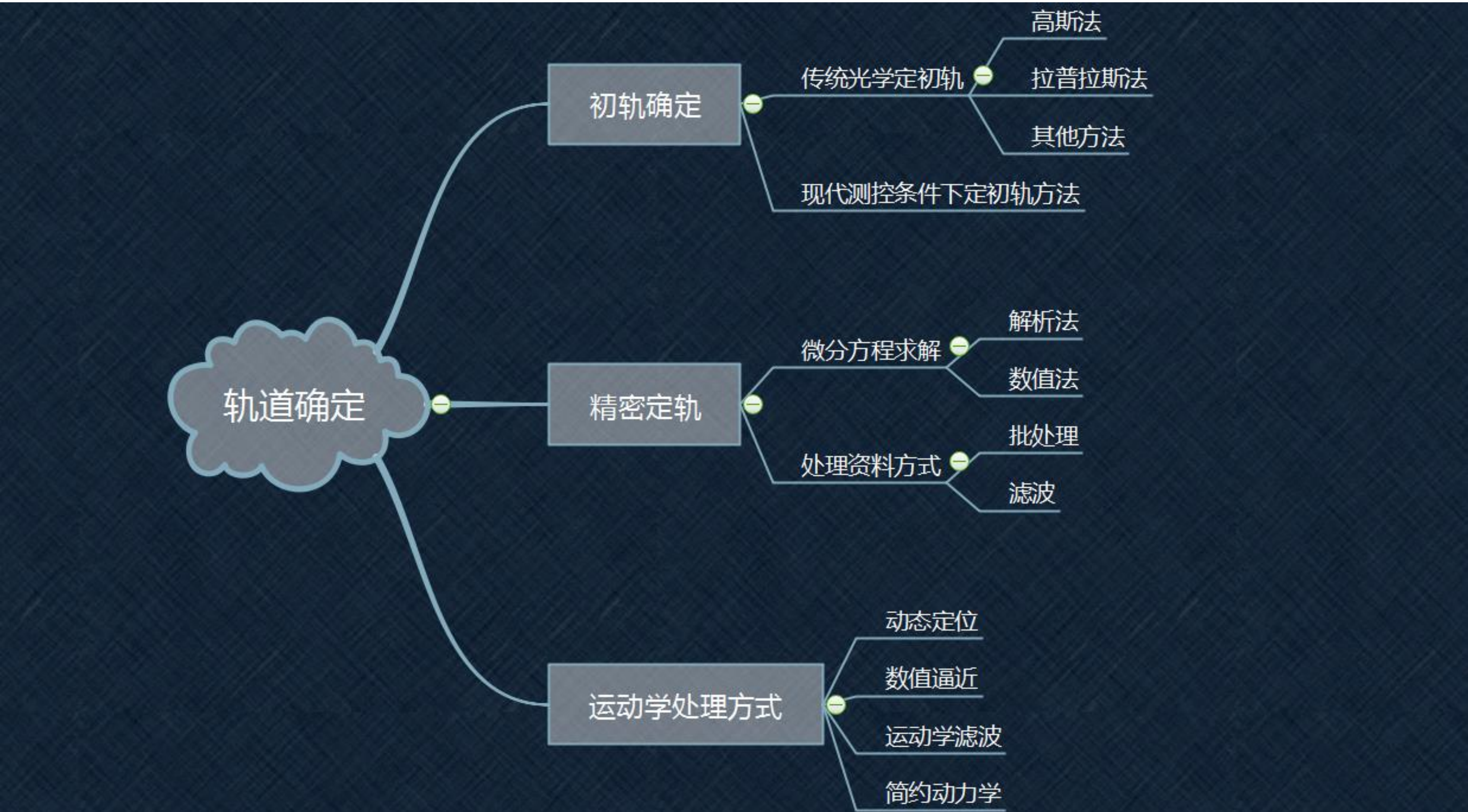
课程主要内容

- 轨道确定问题
- 初轨确定问题
- 精密定轨方法

轨道确定



轨道确定
初轨确定
传统光学定初轨
高斯法
拉普拉斯法
其他方法
现代测控条件下定初轨方法
精密定轨
微分方程求解
解析法
数值法
处理资料方式
批处理
滤波
运动学处理方式
动态定位
数值逼近
运动学滤波
简约动力学

改进拉普拉斯法定初轨（一）

二体F、G级数

$$\begin{cases} \vec{r} = F\ \vec{r}_0 + G\ \dot{\vec{r}}_0 \\ \dot{\vec{r}} = F'\ \dot{\vec{r}}_0 + G'\ \vec{r}_0 \end{cases}$$

$$\begin{cases} F = 1 - \left(\frac{1}{2}u_0\right)\Delta t^2 + \left(\frac{1}{2}u_0 p_0\right)\Delta t^3 + \left(\frac{1}{8}u_0 q_0 - \frac{1}{12}u_0^2 - \frac{5}{8}u_0 p_0^2\right)\Delta t^4 + O\left(\Delta t^5\right) \\ G = \Delta t - \left(\frac{1}{6}u_0\right)\Delta t^3 + \left(\frac{1}{4}u_0 p_0\right)\Delta t^4 + O\left(\Delta t^5\right) \end{cases}$$

$$u_0 = 1/r_0^3,\quad p_0 = \vec{r}_0\dot{\vec{r}}_0/r_0^2,\quad q_0 = v_0^2/r_0^2$$

$$\begin{cases} F = 1 - \frac{a}{r_0}(1 - \cos\Delta E) \\ G = \Delta t - \frac{1}{n}(\Delta E - \sin\Delta E) \end{cases}$$

$$\begin{cases} F = 1 + O\left(\Delta t^2\right), \\ G = \Delta t\left[1 + O\left(\Delta t^2\right)\right] \end{cases}$$

$$\begin{aligned} F = 1 &+ \frac{\tau^2}{2}\left[-u^3 + \left(\frac{3J_2}{2}\right)(5u_7 z_0^2 - u_5) - \mu' u_3'\right] \\ &+ \frac{\tau^3}{6}\left[(3u_5\sigma) + \left(\frac{3J_2}{2}\right)(5(u_7 - 7u_9 z_0^2)\sigma + 10u_7 z_0 \dot{z}_0)\right] \\ &+ \frac{\tau^4}{24}\left[u_5(3v_0^2 - 2u_1 - 15u_2\sigma^2) + \left(\frac{3J_2}{2}\right)(6u_8(4u_2 z_0^2 - 1) - 5u_7(7u_2 z_0^2 - 1)v_0^2\right. \\ &\left.+ 10u_7 \dot{z}_0^2 + 35u_9(9u_2 z_0^2 - 1)\sigma^2 - 140u_9\sigma z_0 \dot{z}_0) + u_3(\mu' u_{3'})\right] \\ &+ \frac{\tau^5}{120}u_7[15\sigma(-3v_0^2 + 2u_1 + 7u_2\sigma^2)] + O(\tau^6) \end{aligned}$$

$$\begin{aligned} G = \tau &+ \frac{\tau^3}{6}\left[-u_3 + \left(\frac{3J_2}{2}\right)(5u_7 z_0^2 - u_5) - \mu' u_{3'}\right] \\ &+ \frac{\tau^4}{24}\left[6u_5\sigma + \left(\frac{3J_2}{2}\right)(20u_7 z_0 \dot{z}_0 - 10u_7(7u_2 z_0^2 - 1)\sigma)\right] \\ &+ \frac{\tau^5}{120}u_5[9v_0^2 - 8u_1 - 45u_2\sigma^2] + O(\tau^6) \end{aligned}$$

改进拉普拉斯法（二）

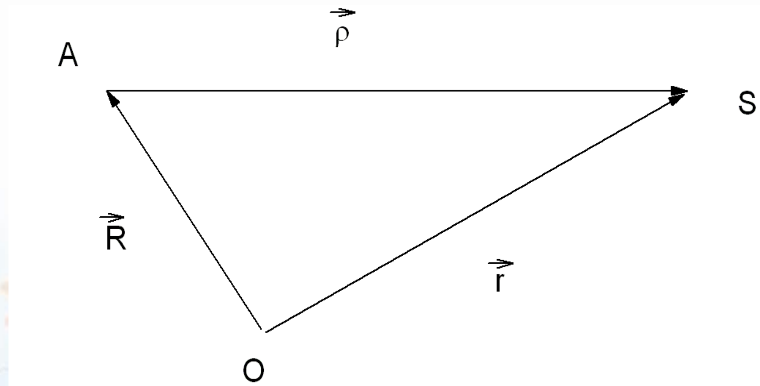
初轨确定和精密定轨的区别？
1.条件与目的
2.从非线性系统的收敛性角度

$$\vec{r} = \vec{\rho} + \vec{R} \qquad \vec{\rho} = \rho\hat{L}, \quad \hat{L} = (\lambda, \mu, \nu)^T$$

$$\hat{L} = \begin{pmatrix} \lambda \\ \mu \\ \nu \end{pmatrix} = \begin{pmatrix} \cos\delta\cos\alpha \\ \cos\delta\sin\alpha \\ \sin\delta \end{pmatrix}$$

拉普拉斯方法的关键：
1.消除距离变量
2.F/G一阶项对短弧是很好的近似

$$\vec{r}(t) = F^*(\vec{r}_0, \dot{\vec{r}}_0, \Delta t)\vec{r}_0 + G^*(\vec{r}_0, \dot{\vec{r}}_0, \Delta t)\dot{\vec{r}}_0$$



$$\hat{L} \times (F^*\vec{r}_0 + G^*\dot{\vec{r}}_0) = \hat{L} \times \vec{R}$$

$$\begin{cases} (F\nu)x_0 - (F_z\lambda)z_0 + (G\nu)\dot{x}_0 - (G_z\lambda)\dot{z}_0 = (\nu X_e - \lambda Z_e) \\ (F\nu)y_0 - (F_z\mu)z_0 + (G\nu)\dot{y}_0 - (G_z\mu)\dot{z}_0 = (\nu Y_e - \mu Z_e) \\ (F\mu)x_0 - (F\lambda)y_0 + (G\mu)\dot{x}_0 - (G\lambda)\dot{y}_0 = (\mu X_e - \lambda Y_e) \end{cases}$$

定初轨时，以上“线性系统”只是形式上是线性的，实际上是非线性的，其系数是轨道（待估）的函数。需要通过迭代完成初轨的改进。

$$\begin{cases} F^0 = 1 - \dfrac{1}{2r_0^3}\Delta t^2 \\ G^0 = \Delta t - \dfrac{\Delta t^3}{6r_0^3} \end{cases}$$

对于无任何先验信息的初轨确定，第一次迭代非常关键。从第二次迭代开始F、G可以用封闭表达式代替级数。

样条基的构造

$$N_{i,2}(u)=\frac{u-u_i}{u_{i+2}-u_i}N_{i,1}(u)+\frac{u_{i+3}-u}{u_{i+3}-u_{i+1}}N_{i+1,1}(u)$$

$$=\begin{cases}\dfrac{(u-u_i)^2}{(u_{i+1}-u_i)(u_{i+2}-u_i)}, & u\in[u_i,u_{i+1})\\ \dfrac{(u-u_i)(u_{i+2}-u)}{(u_{i+2}-u_i)(u_{i+2}-u_{i+1})}+\dfrac{(u-u_{i+1})(u_{i+3}-u)}{(u_{i+2}-u_{i+1})(u_{i+3}-u_{i+1})}, & u\in[u_{i+1},u_{i+2})\\ \dfrac{(u_{i+3}-u)^2}{(u_{i+3}-u_{i+1})(u_{i+3}-u_{i+2})}, & u\in[u_{i+2},u_{i+3})\\ 0, & \text{其他}\end{cases}$$

B样条基函数具有局部支集性

$$N'_{i,p}(u)=\frac{p}{u_{i+p}-u_i}N_{i,p-1}(u)-\frac{p}{u_{i+p+1}-u_{i+1}}N_{i+1,p-1}(u)$$

$$N_{i,3}(u)=\frac{u-u_i}{u_{i+3}-u_i}N_{i,2}(u)+\frac{u_{i+4}-u}{u_{i+4}-u_{i+1}}N_{i+1,2}(u)$$

$$=\begin{cases}\dfrac{(u-u_i)^3}{(u_{i+1}-u_i)(u_{i+2}-u_i)(u_{i+3}-u_i)}, & u\in[u_i,u_{i+1})\\ \left.\begin{array}{l}\dfrac{(u-u_i)^2(u_{i+2}-u)}{(u_{i+2}-u_i)(u_{i+2}-u_{i+1})(u_{i+3}-u_i)}\\ +\dfrac{(u-u_{i+1})(u_{i+3}-u)(u-u_{i+1})}{(u_{i+2}-u_{i+1})(u_{i+3}-u_{i+1})(u_{i+2}-u_{i+1})}\\ +\dfrac{(u_{i+4}-u)(u-u_{i+1})^2}{(u_{i+2}-u_{i+1})(u_{i+3}-u_{i+1})(u_{i+4}-u_{i+1})}\end{array}\right\}, & u\in[u_{i+1},u_{i+2})\\ \left.\begin{array}{l}\dfrac{(u-u_i)(u_{i+3}-u)^2}{(u_{i+3}-u_i)(u_{i+3}-u_{i+1})(u_{i+3}-u_{i+2})}\\ +\dfrac{(u-u_{i+1})(u_{i+3}-u)(u_{i+4}-u)}{(u_{i+3}-u_{i+1})(u_{i+3}-u_{i+2})(u_{i+4}-u_{i+1})}\\ +\dfrac{(u_{i+4}-u)^2(u-u_{i+2})}{(u_{i+4}-u_{i+1})(u_{i+4}-u_{i+2})(u_{i+3}-u_{i+2})}\end{array}\right\}, & u\in[u_{i+2},u_{i+3})\\ \dfrac{(u_{i+4}-u)^3}{(u_{i+4}-u_{i+1})(u_{i+4}-u_{i+2})(u_{i+4}-u_{i+3})}, & u\in[u_{i+3},u_{i+4})\\ 0, & \text{其他}\end{cases}$$

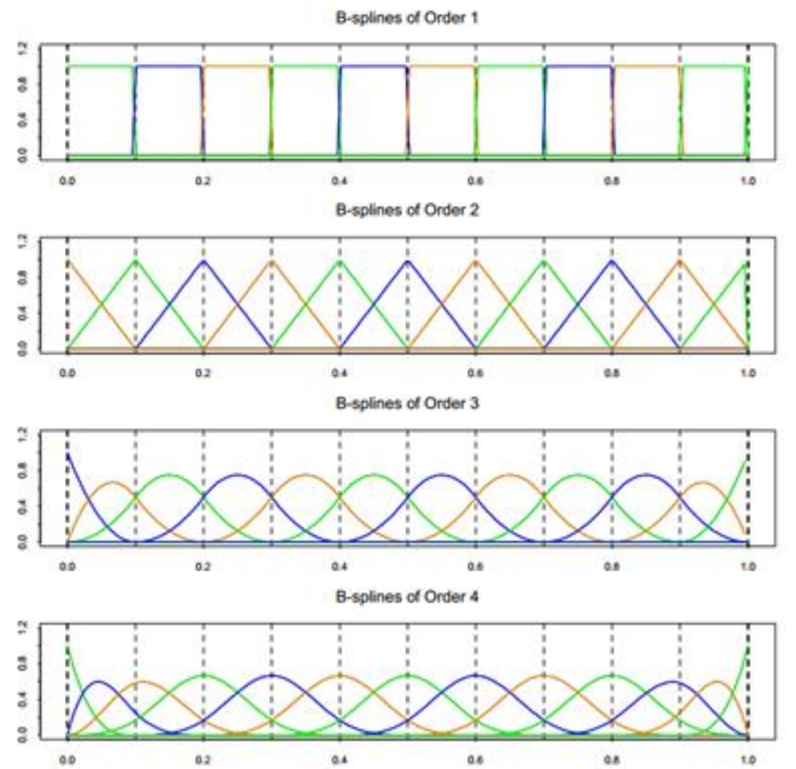
外测弹道确定：样条基构造

$$
\begin{cases}
N_{i,0}(u) = \begin{cases} 1, u \in [u_i, u_{i+1}) \\ 0, otherwise \end{cases} \\
N_{i,p}(u) = \dfrac{u - u_i}{u_{i+p} - u_i} N_{i,p-1}(u) + \dfrac{u_{i+p+1} - u}{u_{i+p+1} - u_{i+1}} N_{i,p-1}(u), p \ge 1
\end{cases}
$$

$$
B_k = \frac{\sum_{j=0}^{k+1} (-1)^j \binom{k+1}{j} \left(x + \frac{k+1}{2} - j \right)_+^k}{k!}
$$

$$
u_+^0 = \begin{cases} 1, (u > 0) \\ \dfrac{1}{2}, (u = 0) \\ 0, (u < 0) \end{cases}
\qquad
u_+^m = \begin{cases} u^m, (u \ge 0) \\ 0, (u < 0) \end{cases}, (m = 1, 2, \ldots)
$$

$N_{0,0}$			
	$N_{0,1}$		
$N_{1,0}$		$N_{0,2}$	
	$N_{1,1}$		$N_{0,3}$
$N_{2,0}$		$N_{1,2}$	
	$N_{2,1}$		$N_{1,3}$
$N_{3,0}$		$N_{2,2}$	$\vdots$
	$N_{3,1}$	$\vdots$	
$N_{4,0}$	$\vdots$		
$\vdots$			



The sequence of B-splines up to order four with ten knots evenly spaced from 0 to 1. The B-splines have local support; they are nonzero on an interval spanned by $M+1$ knots.

外测弹道确定：样条弹道逼近

$$\begin{cases} x(t)=\sum_{j=1}^{P}\alpha_j B\left(\frac{t-T_j}{h}\right),\ \ x(t)=\sum_{j=1}^{P}\frac{\alpha_j B\left(\frac{t-T_j}{h}\right)}{h} \\ y(t)=\sum_{j=1}^{P}\beta_j B\left(\frac{t-T_j}{h}\right),\ \ y(t)=\sum_{j=1}^{P}\frac{\beta_j B\left(\frac{t-T_j}{h}\right)}{h}, \\ z(t)=\sum_{j=1}^{P}\gamma_j B\left(\frac{t-T_j}{h}\right),\ \ z(t)=\sum_{j=1}^{P}\frac{\gamma_j B\left(\frac{t-T_j}{h}\right)}{h} \end{cases}$$

$$\begin{cases} h=\frac{(T_{P-1}-T_2)}{P-3} \\ T_j=T_2+(j-2)h \end{cases}$$

$$B_3=\begin{cases} 0,\left(|x|\ge 2\right) \\ \frac{1}{2}|x|^3-x^2+\frac{2}{3},\left(|x|\le 1\right) \\ -\frac{1}{6}|x|^3+x^2-2|x|+\frac{4}{3},\left(1<|x|<2\right) \end{cases}$$

$$B_3(x)=\begin{cases} 0 & ,\ |x|\ge 2 \\ \left.\begin{cases} \frac{3}{2}|x|^2-2x & ,x>0 \\ -\frac{3}{2}|x|^2-2x & ,x<0 \end{cases}\right\rangle & ,\ \ |x|<1 \\ \left.\begin{cases} -\frac{1}{2}|x|^2+2x-2 & ,x>0 \\ \frac{1}{2}|x|^2+2x+2 & ,x<0 \end{cases}\right\rangle & ,1\le|x|<2 \end{cases}$$

外测弹道确定：线性化方程

$$\boldsymbol{O}\text{-}\boldsymbol{C}=\left[\frac{\partial \boldsymbol{G}}{\partial \boldsymbol{X}}\right]\begin{bmatrix}\boldsymbol{\Xi}\\ \boldsymbol{\Theta}\end{bmatrix}\Delta\boldsymbol{\psi} \qquad \boldsymbol{\psi}=\left[\alpha_1,\cdots,\alpha_P,\beta_1,\cdots,\beta_P,\gamma_1,\cdots,\gamma_P\right]^{\mathrm{T}}$$

$$\begin{cases}\boldsymbol{B}_1=\left[B\left(\frac{t_1-T_1}{h}\right) \quad B\left(\frac{t_1-T_2}{h}\right) \quad \cdots \quad B\left(\frac{t_1-T_P}{h}\right)\right]\\ \boldsymbol{B}_2=\left[B\left(\frac{t_2-T_1}{h}\right) \quad B\left(\frac{t_2-T_2}{h}\right) \quad \cdots \quad B\left(\frac{t_2-T_P}{h}\right)\right]\\ \quad\vdots\\ \boldsymbol{B}_m=\left[B\left(\frac{t_m-T_1}{h}\right) \quad B\left(\frac{t_m-T_2}{h}\right) \quad \cdots \quad B\left(\frac{t_m-T_P}{h}\right)\right]\end{cases}$$

$$\boldsymbol{\Xi}=\begin{bmatrix}\boldsymbol{B}_1 & \boldsymbol{B}_1 & \boldsymbol{B}_1\\ \boldsymbol{B}_2 & \boldsymbol{B}_2 & \boldsymbol{B}_2\\ \vdots & \vdots & \vdots\\ \boldsymbol{B}_m & \boldsymbol{B}_m & \boldsymbol{B}_m\end{bmatrix}$$

线性问题？
初值问题？

$$\begin{cases}\dot{\boldsymbol{B}}_1=\left[\dot{B}\left(\frac{t_1-T_1}{h}\right) \quad \dot{B}\left(\frac{t_1-T_2}{h}\right) \quad \cdots \quad \dot{B}\left(\frac{t_1-T_P}{h}\right)\right]\\ \dot{\boldsymbol{B}}_2=\left[\dot{B}\left(\frac{t_2-T_1}{h}\right) \quad \dot{B}\left(\frac{t_2-T_2}{h}\right) \quad \cdots \quad \dot{B}\left(\frac{t_2-T_P}{h}\right)\right]\\ \quad\vdots\\ \dot{\boldsymbol{B}}_m=\left[\dot{B}\left(\frac{t_m-T_1}{h}\right) \quad \dot{B}\left(\frac{t_m-T_2}{h}\right) \quad \cdots \quad \dot{B}\left(\frac{t_m-T_P}{h}\right)\right]\end{cases}$$

$$\boldsymbol{\Theta}=\frac{1}{h}\begin{bmatrix}\dot{\boldsymbol{B}}_1 & \dot{\boldsymbol{B}}_1 & \dot{\boldsymbol{B}}_1\\ \dot{\boldsymbol{B}}_2 & \dot{\boldsymbol{B}}_2 & \dot{\boldsymbol{B}}_2\\ \vdots & \vdots & \vdots\\ \dot{\boldsymbol{B}}_m & \dot{\boldsymbol{B}}_m & \dot{\boldsymbol{B}}_m\end{bmatrix}$$

$$\begin{cases}X=F_1(\alpha_1,\cdots,\alpha_P),\dot{X}=F_4(\alpha_1,\cdots,\alpha_P)\\ Y=F_2(\beta_1,\cdots,\beta_P),\dot{Y}=F_5(\beta_1,\cdots,\beta_P)\\ Z=F_3(\gamma_1,\cdots,\gamma_P),\dot{Z}=F_6(\gamma_1,\cdots,\gamma_P)\end{cases}$$

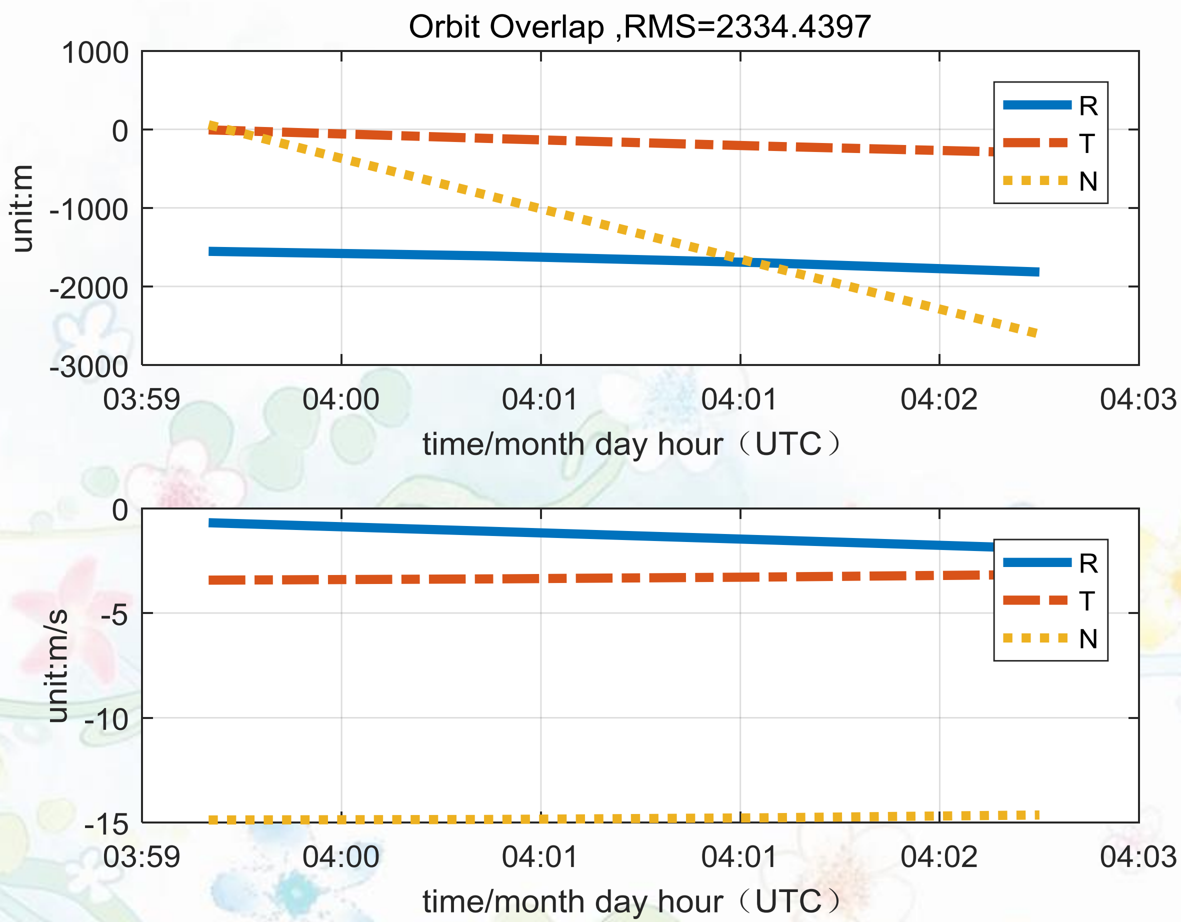
天基平台测角拉普拉斯方法低低模式初轨确定

平台轨道	**高度400km，近圆轨道，倾角42° 。轨道噪声1米。**
目标轨道	高度800km, 近圆轨道，倾角80。
测量数据	采样率1秒，精度0.5角秒。

epoch1	2018.0	8.0	21.0
epoch2	4.0	00.0	00.000
pos 0	7278063.978	-29901.639	-12992.788
vel 0	18.289	1284.862	7288.046

2	pos 0	7298676.644	-30007.840	-13028.426
	vel 0	17.770	1114.764	7364.932
3	pos 0	7276510.626	-29953.685	-12986.493
	vel 0	17.648	1298.911	7282.058
4	pos 0	7244075.551	-29893.627	-12920.345
	vel 0	17.112	1568.733	7160.580
8	pos 0	6512857.661	-37752.246	-10076.740
	vel 0	1.227	7756.661	4390.572

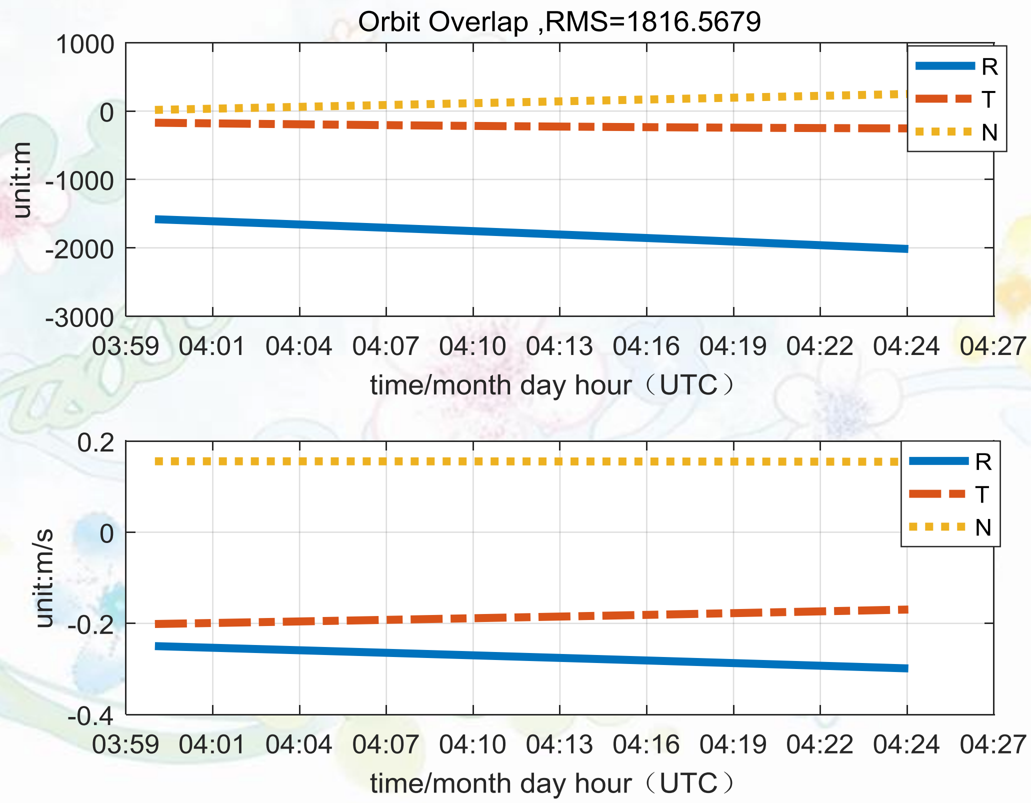
低低模式与仿真轨道比较



低高模式初轨模式

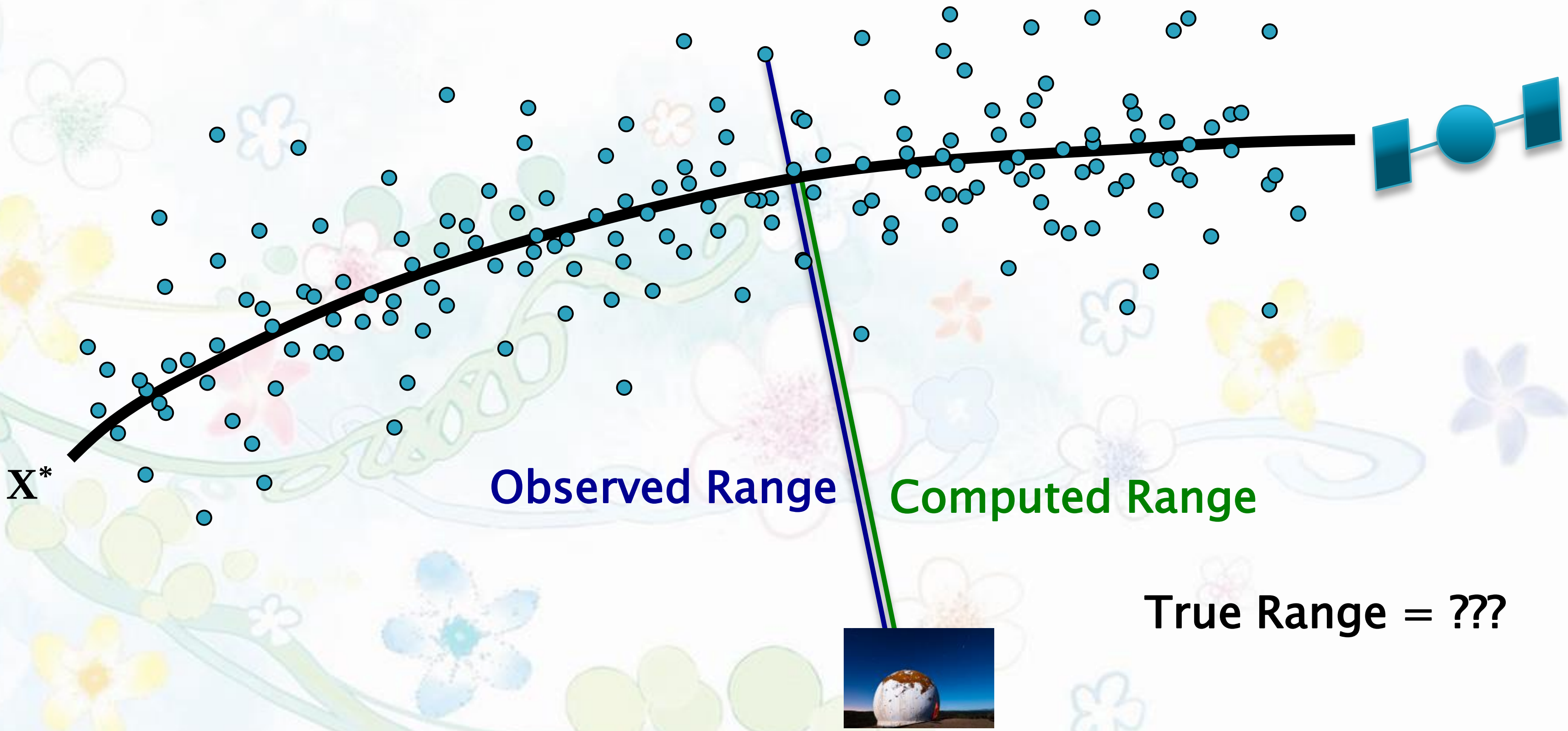
平台轨道	高度400km，近圆轨道，倾角42°。轨道噪声1米。
GEO轨道	星下点经度120°。
测量数据	采样率3秒，精度0.5角秒。

定轨弧长为25分钟时

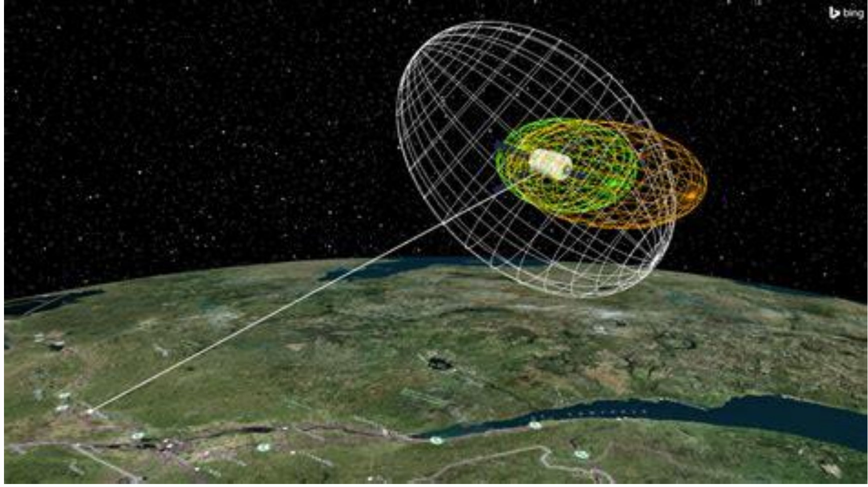


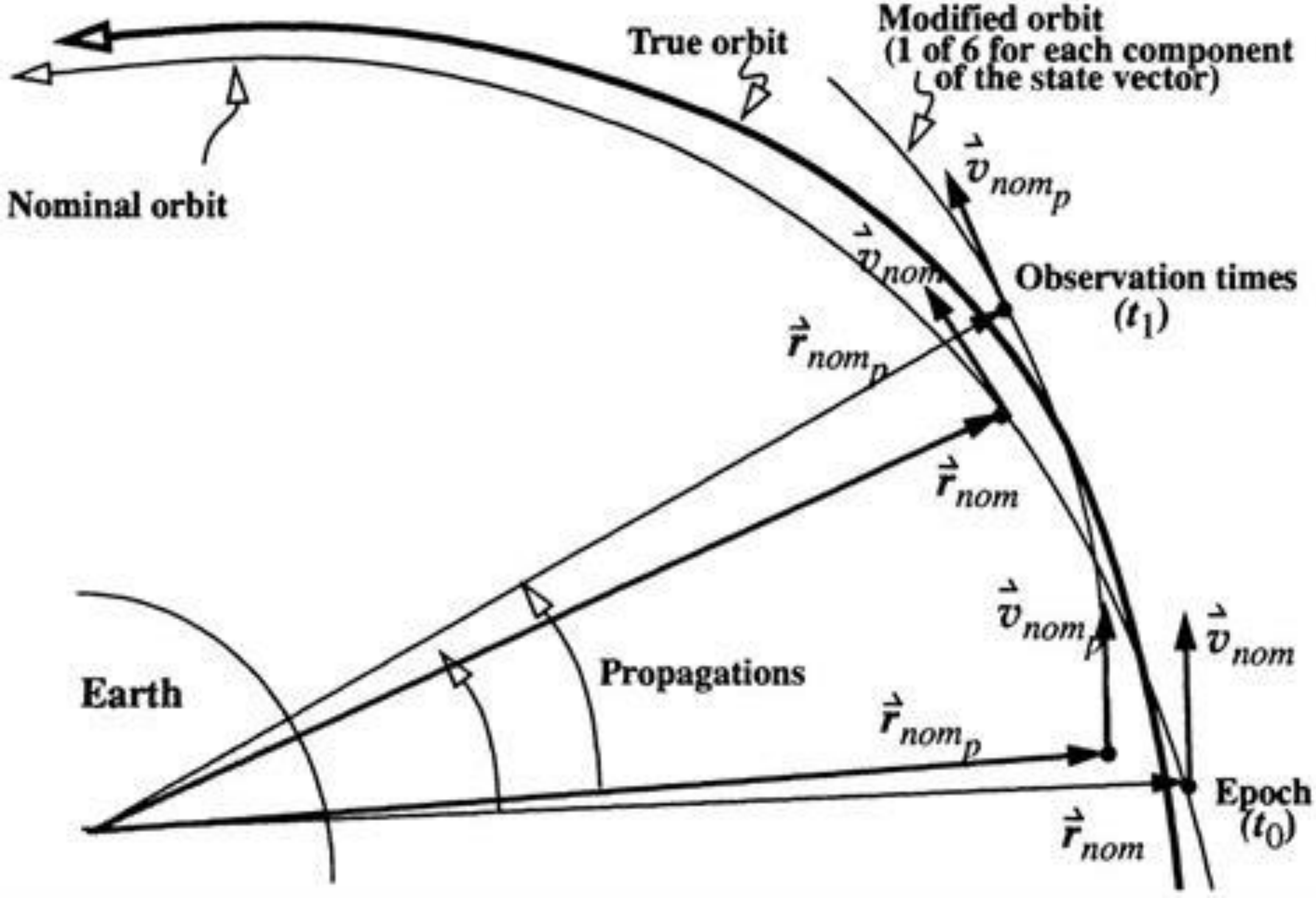
统计定轨问题描述

- 带有观测噪声的动力系统
- 需要用数学手段把各个历元的观测数据都关联到我们要估计的轨道及其他参数



多变元微分改正





True orbit
Modified orbit
(1 of 6 for each component
of the state vector)
Nominal orbit
$\vec{v}_{nom_p}$
$\vec{v}_{nom}$
Observation times
(t_1)
$\vec{r}_{nom_p}$
$\vec{r}_{nom}$
Propagations
Earth
$\vec{v}_{nom_p}$
$\vec{v}_{nom}$
$\vec{r}_{nom_p}$
Epoch
(t_0)
$\vec{r}_{nom}$

一般性动力系统估计问题

$$\dot{\boldsymbol{X}} = F(\boldsymbol{X}, t) + \boldsymbol{u}, \quad \boldsymbol{X}(t_0) = \boldsymbol{X}_0$$

$$\boldsymbol{Y}_i = G(\boldsymbol{X}_i, t_i) + \boldsymbol{\epsilon}_i, \quad i = 1, \ldots, l$$

$$\boldsymbol{X} \in \mathbb{R}^n, \quad \boldsymbol{Y}_i \in \mathbb{R}^p$$

状态向量

观测向量

观测方程和动力学方程有一个是非线性的，则该系统即为非线性系统。通常采用线性化处理。

批处理估计

$$\boldsymbol{y} = H\boldsymbol{x}_0 + \boldsymbol{\epsilon} \quad \Rightarrow \quad \boldsymbol{x}_0 = \left(H^T H\right)^{-1} H^T \boldsymbol{y}$$

$$\boldsymbol{y} \equiv \begin{bmatrix} \boldsymbol{y}_1 \\ \boldsymbol{y}_2 \\ \vdots \\ \boldsymbol{y}_l \end{bmatrix} \qquad H \equiv \begin{bmatrix} \tilde{H}_1 \Phi(t_1, t_0) \\ \tilde{H}_2 \Phi(t_2, t_0) \\ \vdots \\ \tilde{H}_l \Phi(t_l, t_0) \end{bmatrix} \qquad \boldsymbol{\epsilon} \equiv \begin{bmatrix} \boldsymbol{\epsilon}_1 \\ \boldsymbol{\epsilon}_2 \\ \vdots \\ \boldsymbol{\epsilon}_l \end{bmatrix}$$

线性化

$$\boldsymbol{x}(t) = \boldsymbol{X}(t) - \boldsymbol{X}^*(t)$$

$$\boldsymbol{x}_i = \boldsymbol{X}(t_i) - \boldsymbol{X}^*(t_i)$$

$$\boldsymbol{y}_i = \boldsymbol{Y}_i - G(\boldsymbol{X}_i^*, t_i)$$

$$\dot{\boldsymbol{x}} = A(t)\boldsymbol{x}$$

$$\boldsymbol{y}_i = \tilde{H}_i \boldsymbol{x}_i + \epsilon_i$$

$$A(t) = \left[\frac{\partial F(\boldsymbol{X}, t)}{\partial \boldsymbol{X}(t)}\right]^*, \quad \tilde{H}_i = \left[\frac{\partial G(\boldsymbol{X}, t)}{\partial \boldsymbol{X}(t)}\right]_i^*$$

状态转移矩阵

- *线性时变微分方程*

$$\dot{\boldsymbol{x}} = A(t)\boldsymbol{x}$$

- *其解的形式为*

$$\boldsymbol{x}(t) = \Phi(t, t_i)\boldsymbol{x}(t_i)$$

- *$\Phi(t,t_i)$ 是状态转移矩阵* (STM)，将状态 $\boldsymbol{x}(t_i)$ 映射到$\boldsymbol{x}(t)$

状态转移矩阵的微分方程

Constant!

$$\boldsymbol{x}(t) = \Phi(t, t_i)\boldsymbol{x}(t_i) \Rightarrow \dot{\boldsymbol{x}}(t) = \dot{\Phi}(t, t_i)\boldsymbol{x}(t_i)$$

$$\dot{\boldsymbol{x}} = A(t)\boldsymbol{x}$$

$$\dot{\Phi}(t, t_i)\boldsymbol{x}(t_i) = A(t)\Phi(t, t_i)\boldsymbol{x}(t_i)$$

Why?

$$\dot{\Phi}(t, t_i) = A(t)\Phi(t, t_i), \ \Phi(t_i, t_i) = \mathbb{I}_n$$

批处理流程

(A) Initialize for this iteration:

Set $i = 1$. Set $t_{i-1} = t_0$, $\mathbf{X}^*(t_{i-1}) = \mathbf{X}_0^*$, $\Phi(t_{i-1}, t_0) = \Phi(t_0, t_0) = I$.

If there is an *a priori* estimate, set $\Lambda = \overline{P}_0^{-1}$ and set $N = \overline{P}_0^{-1}\bar{\mathbf{x}}_0$.

If there is no *a priori* estimate, set $\Lambda = 0$ and set $N = 0$.

↓

(B) Read the next observation: t_i, $\mathbf{Y}_i$, R_i.

↓

Integrate reference trajectory and state transition matrix from t_{i-1} to t_i.

$\dot{\mathbf{X}}^* = F(\mathbf{X}^*(t), t)$ with initial conditions $\mathbf{X}^*(t_{i-1})$

$A(t) = [\partial F(\mathbf{X}, t)/\partial \mathbf{X}]^*$, where * means evaluated on the nominal trajectory.

$\dot{\Phi}(t, t_0) = A(t)\Phi(t, t_0)$ with initial conditions $\Phi(t_{i-1}, t_0)$.

This gives $\mathbf{X}^*(t_i), \Phi(t_i, t_0)$.

↓

Accumulate current observation

$$\widetilde{H}_i = [\partial G(\mathbf{X}, t_i)/\partial \mathbf{X}]^*$$
$$\mathbf{y}_i = \mathbf{Y}_i - G(\mathbf{X}_i^*, t_i)$$
$$H_i = \widetilde{H}_i \Phi(t_i, t_0)$$
$$\Lambda = \Lambda + H_i^T R_i^{-1} H_i$$
$$N = N + H_i^T R_i^{-1} \mathbf{y}_i$$

↓

If $t_i < t_{\text{final}}$:

$i = i + 1$. Thus:

t_i becomes t_{i-1}

$\mathbf{X}^*(t_i)$ becomes $\mathbf{X}^*(t_{i-1})$

$\Phi(t_i, t_0)$ becomes $\Phi(t_{i-1}, t_0)$

Go to (B) and read the next observation.

If $t_i \geq t_{\text{final}}$:

Go to (C) and solve normal equations.

↓

(C) Solve normal equations.

The normal equations are $\Lambda \hat{\mathbf{x}}_0 = N$. The covariance is $P_0 = \Lambda^{-1}$.

↓

Has process converged?

Yes → STOP

No → Iterate.

Update the nominal trajectory: Replace $\mathbf{X}_0^*$ with $\mathbf{X}_0^* + \hat{\mathbf{x}}_0$.

Shift $\bar{\mathbf{x}}_0$ to be with respect to the updated $\mathbf{X}_0^*$, as follows: $\bar{\mathbf{x}}_0 = \bar{\mathbf{x}}_0 - \hat{\mathbf{x}}_0$.

Use the original value of $\overline{P}_0$.

Go to (A) and use the new values for $\mathbf{X}_0^*$ and $\bar{\mathbf{x}}_0$.

→ to (A)


Q&A!