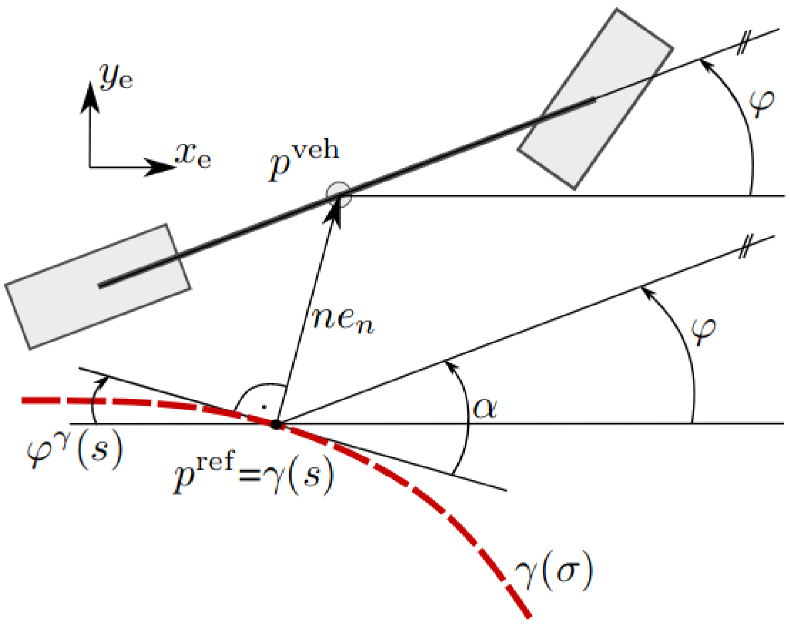
面向城市 NOH 的时空联合决策规划算法开发

1. 模型建立



2. Lifted ODE

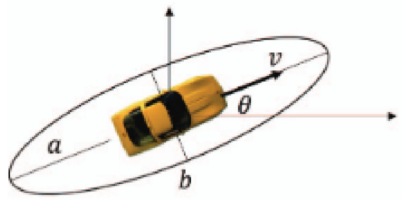
[【自动驾驶】Frenet坐标系与Cartesian坐标系(一)-CSDN博客]

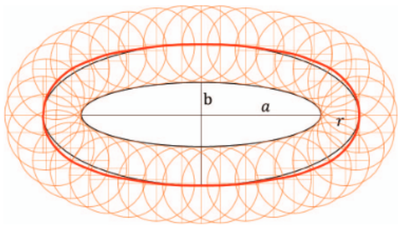
$$State: \begin{pmatrix} \dot{s} \\ \dot{n} \\ \dot{\alpha} \\ \dot{x} \\ \dot{y} \\ \dot{v} \\ \dot{\phi} \end{pmatrix} = \begin{pmatrix} \frac{v\cos(\alpha)}{1-\kappa n} \\ v\sin(\alpha) \\ \dot{\phi} - \frac{\kappa v\cos(\alpha)}{1-\kappa n} \\ v\cos(\phi) \\ v\sin(\phi) \\ a \\ \dot{\phi} \end{pmatrix} ;\ Input: \begin{pmatrix} a \\ \dot{\phi} \end{pmatrix}$$

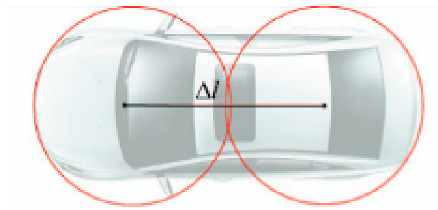
$$\dot{X} = \begin{pmatrix} 0 & \frac{\kappa v\cos(\alpha)}{(1-\kappa n)^2} & -\frac{v\sin(\alpha)}{1-\kappa n} & 0 & 0 & \frac{\cos(\alpha)}{1-\kappa n} & 0 & 0 & 0 \\ 0 & 0 & v\cos(\alpha) & 0 & 0 & \sin(\alpha) & 0 & 0 & 0 \\ 0 & -\frac{\kappa^2 v\cos(\alpha)}{(1-\kappa n)^2} & \frac{\kappa v\sin(\alpha)}{1-\kappa n} & 0 & 0 & -\frac{\kappa\cos(\alpha)}{1-\kappa n} & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & \cos(\phi) & -v\sin(\phi) & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \sin(\phi) & v\cos(\phi) & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

3. Safety Boundary

3.1 车辆包络







$$P=(P_x,P_y)$$
$$f_{collision}=1-(x_k-x_0)^T P(x_k-x_0)<0$$

3.2 Road boundary

$$min_{offset}<n<max_{offset}$$

4. Cost

$$Cost_{total}=Cost_{input}+Cost_n+Cost_{dis2obs}+Cost_{err_v}$$
$$=a^2+\dot{\phi}^2+n^2+$$
$$\frac{1}{exp^{-\frac{t_i}{\lambda}}*\frac{(\cos obs_\phi(x_{obs}-x_{ego})-\sin(obs_\phi)(y_{obs}-y_{ego}))^2}{a^2}+\frac{(\sin(obs_\phi)(x_{obs}-x_{ego})+\cos(obs_\phi)(y_{obs}-y_{ego}))^2}{b^2}}+$$
$$\begin{cases} w_+ * err_v^2, & if(err_v>0)\\ w_- * err_v^2, & if(err_v<0)\end{cases}$$

整体表述

$$\min_{\substack{x_0^{\mathrm{d}},\ldots,x_N^{\mathrm{d}},\\ u_0,\ldots,u_{N-1}\\ \theta_1,\ldots,\theta_{n_{\mathrm{opp}}}}} \sum_{k=0}^{N-1}\|u_k\|_R^2+\left\|x_k^{\mathrm{F}}-x_{\mathrm{ref},k}^{\mathrm{F}}\right\|_Q^2+\left\|x_N^{\mathrm{F}}-x_{\mathrm{ref},N}^{\mathrm{F}}\right\|_{Q_N}^2+\left\|\frac{1}{exp^{\frac{t}{\lambda}}*dis(x_k^{c,opp,j},\theta_{n_{opp}})}\right\|^2$$

$$\begin{aligned}
&\text{s.t.}\\
&x_0^{\mathrm{d}}=\bar{x}_0^{\mathrm{d}},\\
&x_{i+1}^{\mathrm{d}}=\Phi^{\mathrm{d}}\left(x_i^{\mathrm{d}},u_i,\Delta t\right),i=0,\ldots,N-1,\\
&\underline{u}\leq u_i\leq\bar{u},\quad i=0,\ldots,N-1,\\
&\underline{x}^{\mathrm{d}}\leq x_i^{\mathrm{d}}\leq\bar{x}^{\mathrm{d}},\quad i=0,\ldots,N,\\
&x_i^{\mathrm{c,C}}\in\mathcal{P}\left(x_i^{\mathrm{c,opp,j}},\theta_j\right),i=0,\ldots,N-1,j=1,\ldots,n_{\mathrm{opp}}.
\end{aligned}$$

🌅 整体思路

- **建模和优化：**结合 Frenet 和 Cartesian 坐标系建立**扩展 ODE** 模型，基于此模型构建 **NMPC** 优化问题，实现 XYT 坐标系下**时空联合规划**
- **求解算法：**采用 **iLQR 算法**求解非线性优化问题，运用 **multiple shooting 方法**处理动力学约束，应用**增广拉格朗日方法**和**投影法**来处理等式和不等式约束