Social-aware Planning and Control for Automated Vehicles Based on Driving Risk Field and Model Predictive Contouring Control

Driving through Roundabouts as a Case Study

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Social-aware Planning and Control for Automated Vehicles Based on Driving Risk Field and Model Predictive Contouring Control: Driving through Roundabouts as a Case Study

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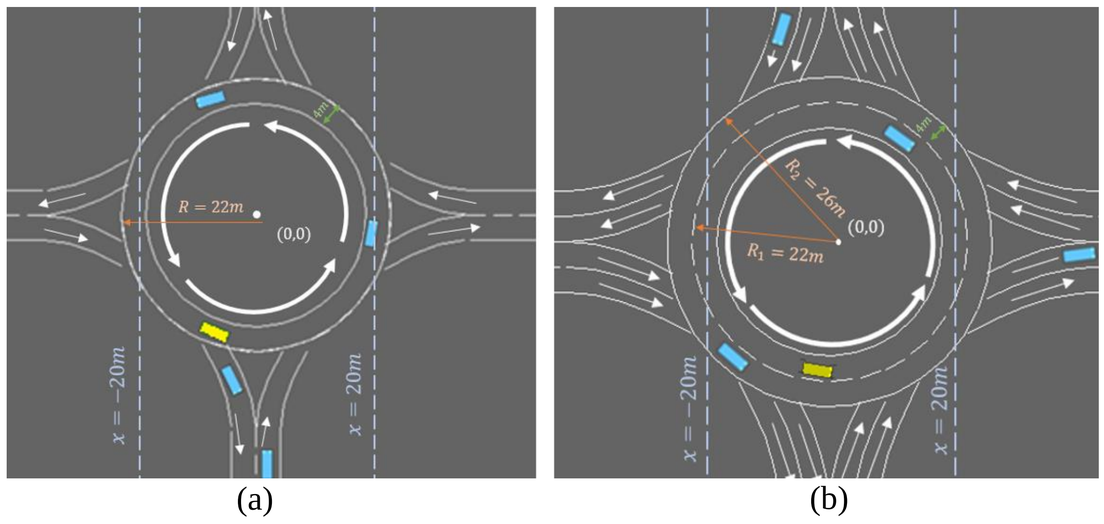
Background

- ❖ Using pure MPC is difficult to take into account other vehicles on the road
- ❖ Few studies implemented integrated planning and control together
- ❖ Methods seldom tackle challenging maneuver of driving through roundabouts
- ❖ Social-aware driving is essential in mixed traffic while rarely being tackled

Main aims

- ➢ **To integrate motion planning and feedback control simultaneously**
- ➢ **To handle potential conflicts with surrounding human-driven vehicles (HDVs) considering their different levels of interests, and generate social-aware driving**
- ➢ **To effectively control the automated vehicle driving through roundabouts safely**



(a) (b)

Figure 1. Illustration of (a) single-lane roundabout and (b) two-lane roundabout

Social-aware DRF-SVO-MPCC implementation

- ➢ **Model Predictive Control (MPC)**
  - ◆ **Cost Function:** $min \ \sum_{k=0}^{N_P-1} J_k\left(X_k, U_k, X_k^{ref}\right), k = 0, \dots, N_P - 1$
- ➢ **Model Predictive Contouring Control (MPCC)**
  - ◆ $\boldsymbol{J_{self}} = J_{mpcc} + J_{comf}$
  - ◆ $J_{comf} = \sum_{k=1}^{N_P} \|u_k - u_{k-1}\|_S^2$
  - ◆ $J_{mpcc} = \sum_{k=2}^{N_P+1}\left(q_c\hat{E}_{ck}^2 + q_l\hat{E}_{lk}^2 + q_o\hat{E}_{ok}^2 + q_{la,ck}\hat{E}_{la,ck}^2\right) - \sum_{k=1}^{N_P} q_v\dot{\theta}_k$
- ➢ **Driving Risk Field (DRF)**
  - ◆ $DRF(x_o, y_o) = a \exp\left(\frac{-\left(\sqrt{(x_o-x_c)^2+(y_o-y_c)^2}-R\right)^2}{2\sigma^2}\right)$
  - ◆ $\boldsymbol{J_{other}} = m_{total}\left(|v_1 - v_2|\right) * DRF_{other}$
- ➢ **Social Value Orientation (SVO)**
  - ◆ $J_{total} = \cos\ \alpha * \boldsymbol{J_{self}} + \sin\alpha\ * \boldsymbol{J_{other}}$

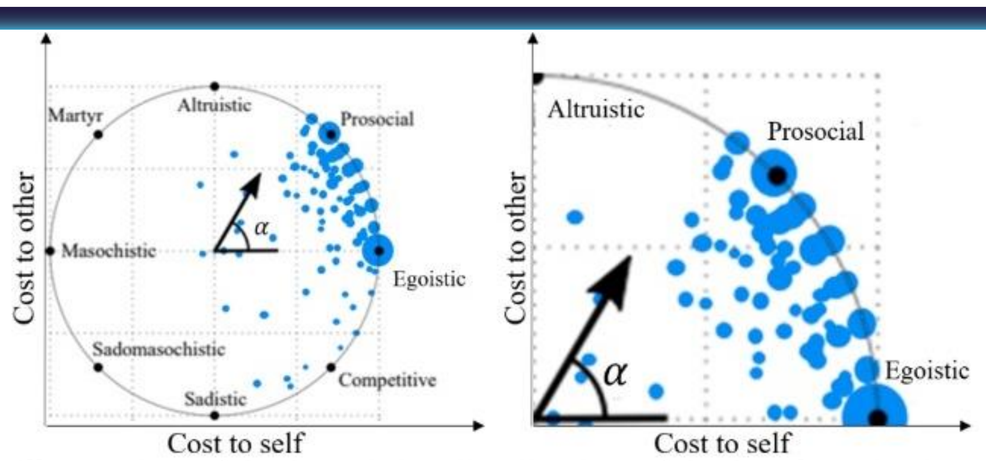
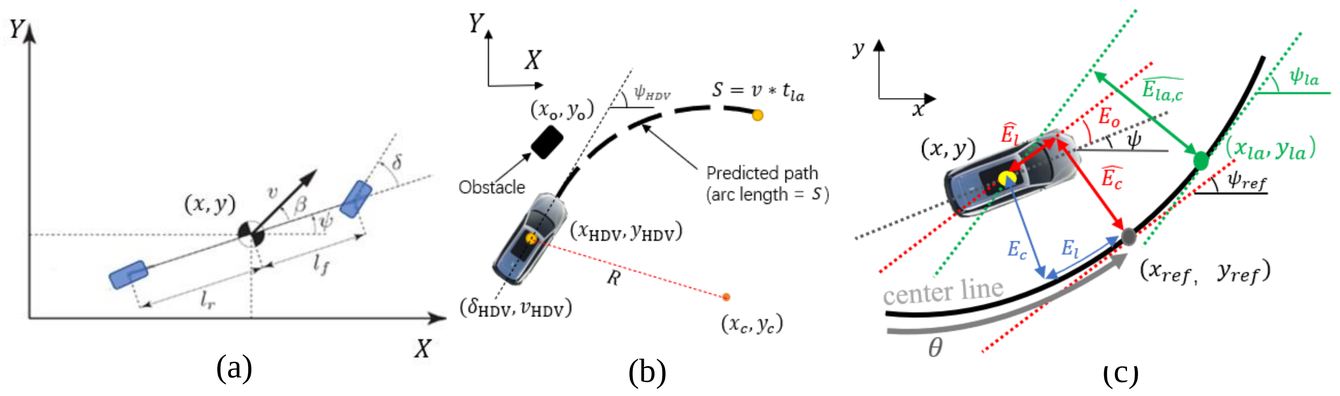


Figure 2. Illustration of SVO and the distribution of SVO values in the population



(a) (b) (c)

Figure 3. Illustration of (a) Predictive model, DRF (b) and MPCC (c)

Results

Table 1. Quantitative Results of The Experiments (AV enters the roundabout first)

Scenarios	Method	Driving styles	Max positional error	Average positional error	Collision
Single-lane roundabout with no HDV	PP Controller	---	$3.08m$	$1.37m$	---
	NMPC	---	$1.27m$	$0.65m$	---
	DRF-SVO-MPCC	---	$\mathbf{0.23m}$	$\mathbf{0.12m}$	---
Single-lane roundabout interacting with an HDV	NMPC	---	---	---	Yes
	DRF-SVO-MPCC	Prosocial	$\mathbf{0.19m}$	$\mathbf{0.09m}$	No
		Egoistic	$0.28m$	$0.16m$	No
Two-lane roundabout interacting with an HDV	NMPC	---	---	---	Yes
	DRF-SVO-MPCC	Prosocial	$\mathbf{0.26m}$	$\mathbf{0.17m}$	No
		Egoistic	$0.34m$	$0.22m$	No

Table 2. Quantitative Results of The Experiments (HDV enters the roundabout first)

Scenarios	Method	Driving styles	Start Braking Distance	Min. distance to HDV	Min. Velocity
Two-lane roundabout interacting with an HDV	**DRF-SVO-MPCC**	Prosocial	$18.22m$	$8.49m$	$1.47m/s$
		Egoistic	$13.87m$	$3.65m$	$3.17m/s$

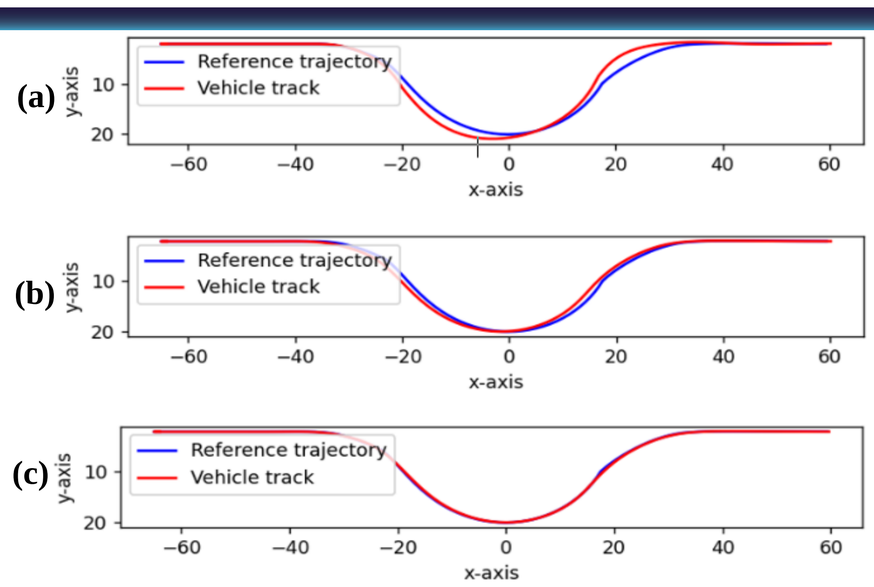


Figure 4. The paths obtained by using the (a) PP controller, (b) NMPC, and (c) Social-aware DRF-SVO-MPCC in comparison to the reference trajectory

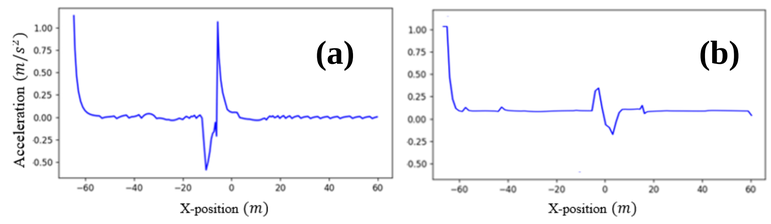


Figure 5. Illustration of the acceleration in different driving styles when passing the two-lane roundabout (a) Prosocial driving (b) Egoistic driving

Summary

- ➢ **This study implements two types of social-aware driving styles, i.e., prosocial and egoistic.**
- ➢ **The model-based DRF-SVO is packaged into the cost function established by MPCC to deliver integrated planning and control.**
- ➢ **DRF-SVO-MPCC model is verified on various simulation experiments comparing with two baselines which demonstrates its good planning and control performance driving through both single-lane and two-lane roundabouts with or without interacting with HDVs.**

Demo Video