The University of Texas at Austin
Cockrell School of Engineering

Sept.29 2023

MASTER’S RESEARCH RECAP

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Robot navigating among pedestrians

- **Research on Pedestrians – Behavior modeling and prediction**
  - Accuracy: Interaction among agents
  - Real-time Capability: Prerequisite for robot navigation
- **Research on Mobile Robots – Control strategy design**
  - Safeness: Top priority
  - Efficiency in task completion

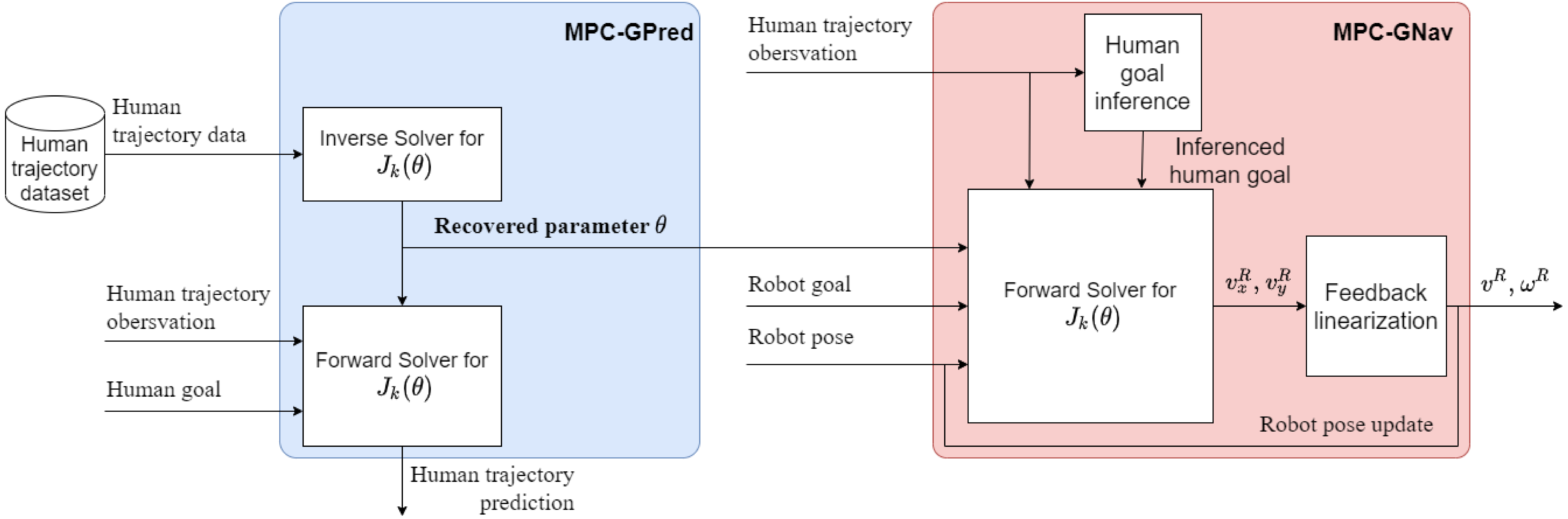
Methodology: forward game & inverse game

➢Pedestrian Trajectory Prediction——MPC-GPred

- Accuracy
- Real-time Capability

➢Robot Navigation——MPC-GNav

- Safeness
- Time efficiency



Overall Framework

Parameter identification via inverse dynamic game

- Existing Problems：
  - Inaccuracy in prediction from a given model
- Parameter Identification via inverse dynamic game：
  - Identify θ that can best describe the observation y^i_{t+1}

$$\min_{\theta,\boldsymbol{\lambda},\boldsymbol{x}} Loss = \sum_t \sum_{i=1}^{M} \left\| x^i_{t+1} - \mathbb{E}\left[x^i_{t+1|t} \middle| x_t\right] \right\|^2$$

$$= \sum_t \sum_{i=1}^{M} \left\| \mathbb{E}\left[y^i_{t+1}\right] - \mathbb{E}\left[x^i_{t+1|t} \middle| x_t\right] \right\|^2$$

$$\begin{aligned} s.t. \quad F_t(\theta) \cdot S_t &= C_t(\theta), \\ \theta_1 &\geq 0, \\ \theta_2 &> 0. \end{aligned}$$

Pedestrian trajectory prediction experiment

- Indoor Pedestrian Trajectory Dataset
- Size

$5.5m \times 4.5m$

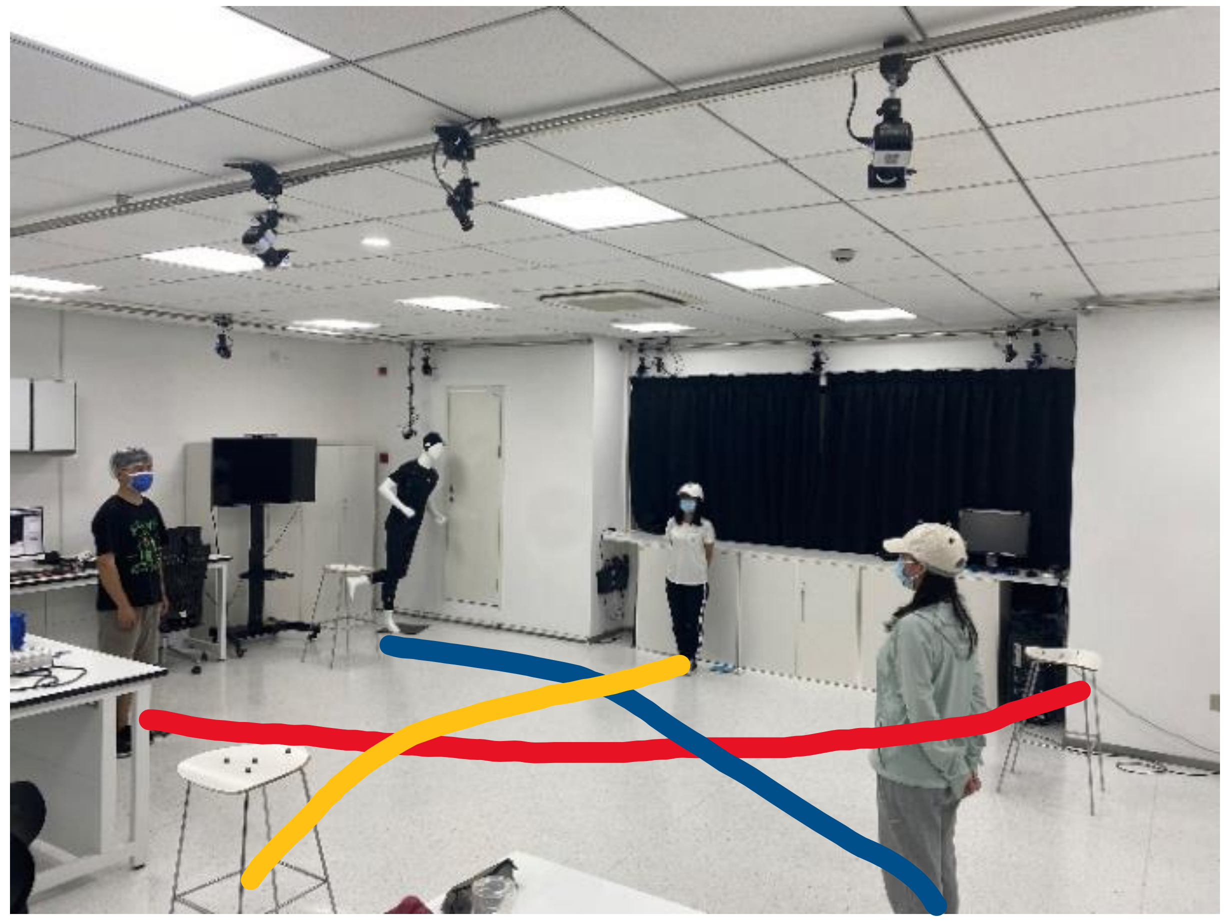
- Ground Truth Measurement

VICON System（$\pm 0.1mm$）

- Dataset Info

No.1-No.50： Intersection

No.51-No.100：Crossing



Intersection

Crossing

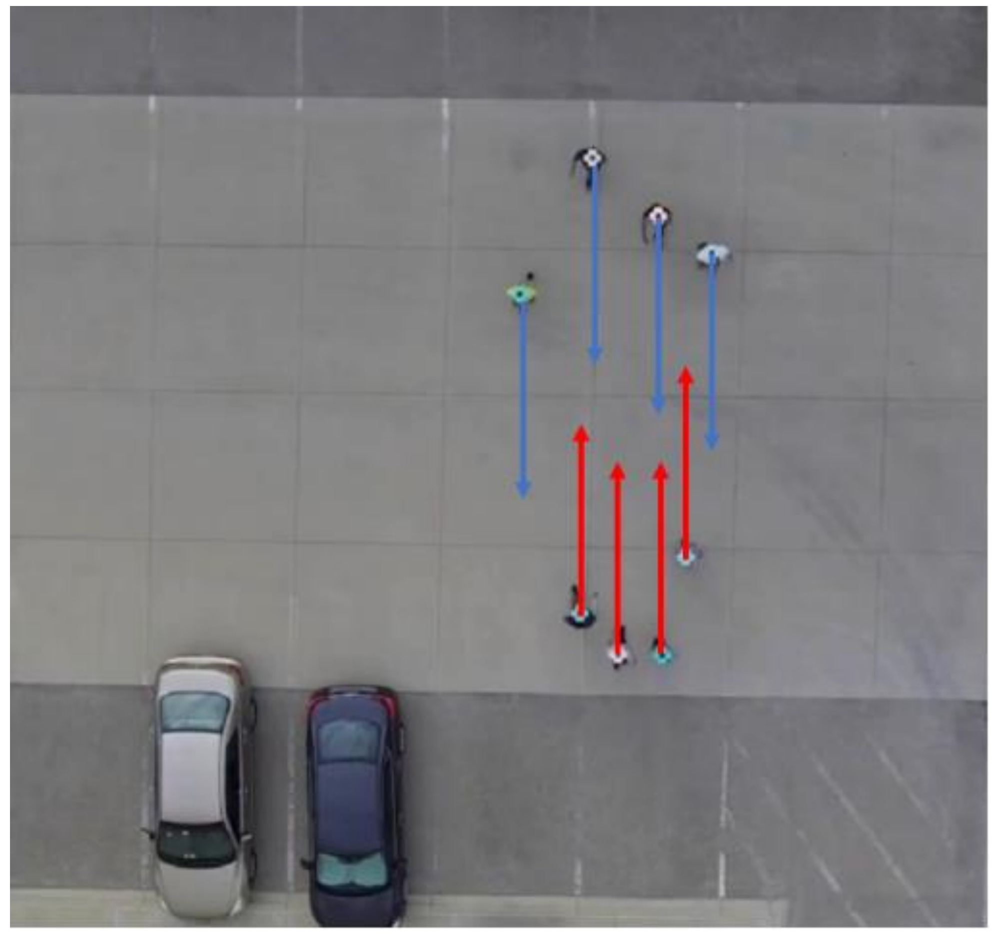
- CITR Dataset[4]
- Size

$10m \times 25m$

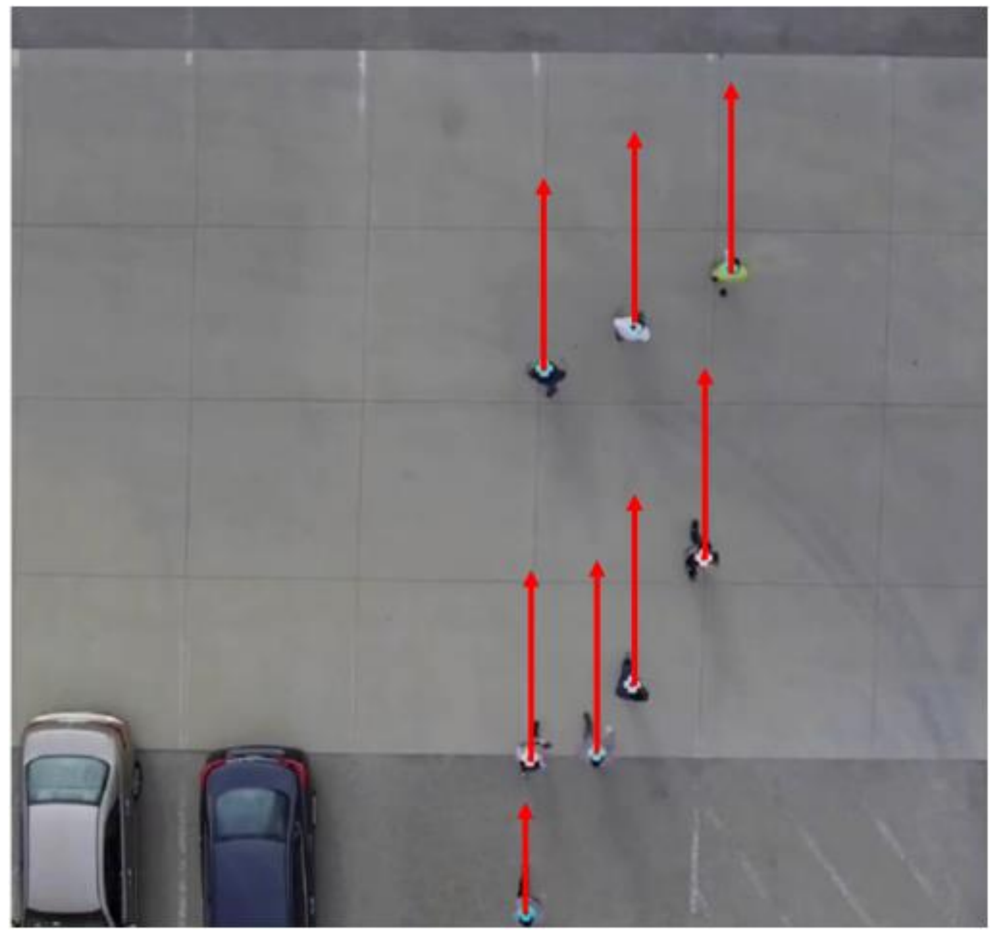
- Dataset Info

No.1-No.8： Bidirectional

No.9-No.12：Unidirectional



Bidirectional



Unidirectional

[1] Yang D, Li L, Redmill K, et al. Top-view trajectories: A pedestrian dataset of vehicle-crowd interaction from controlled experiments and crowded campus[C]//2019 IEEE Intelligent Vehicles Symposium (IV). IEEE, 2019: 899-904.

Pedestrian trajectory prediction experiment

➢Training Data：

IPT Dataset No.1-No.35, No.51-No.85;

CITR Dataset No.1-No.6, No.9-No.11

➢Test Data：

IPT Dataset No.36-No.50, No.86-No.100;

CITR Dataset No.7,No.8, No.12

➢Parameter Setting：

$\Delta t = 0.1[sec]$

$\Sigma_w = 3 \times 10^{-4} \cdot I\ [m \times m]$

$T = 2$ [sec]

➢Evaluation Metric：

Average Displacement Error: ADE [m] [4]

Final Displacement Error: FDE [m] [4]

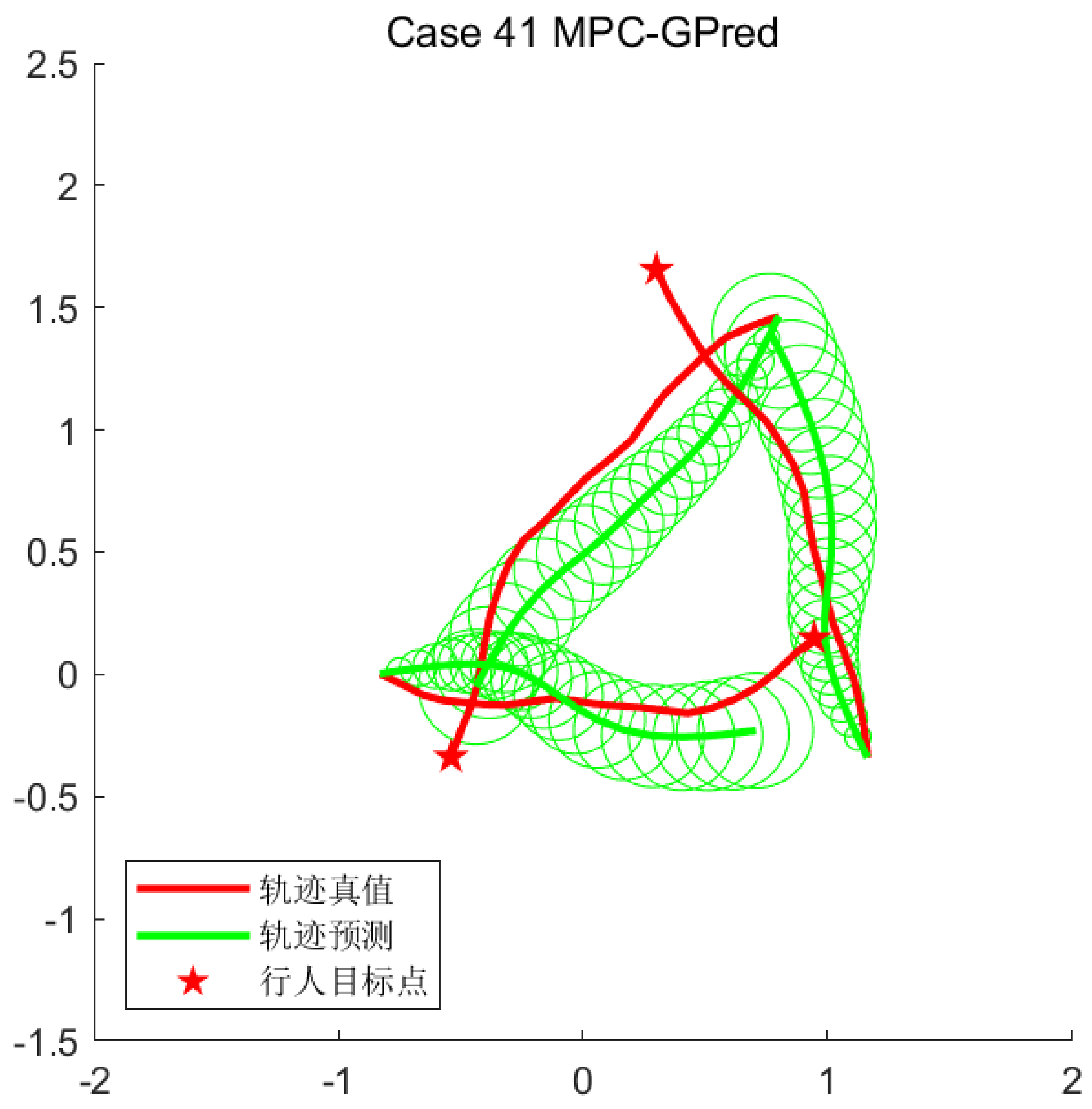
Calucation Time [sec]

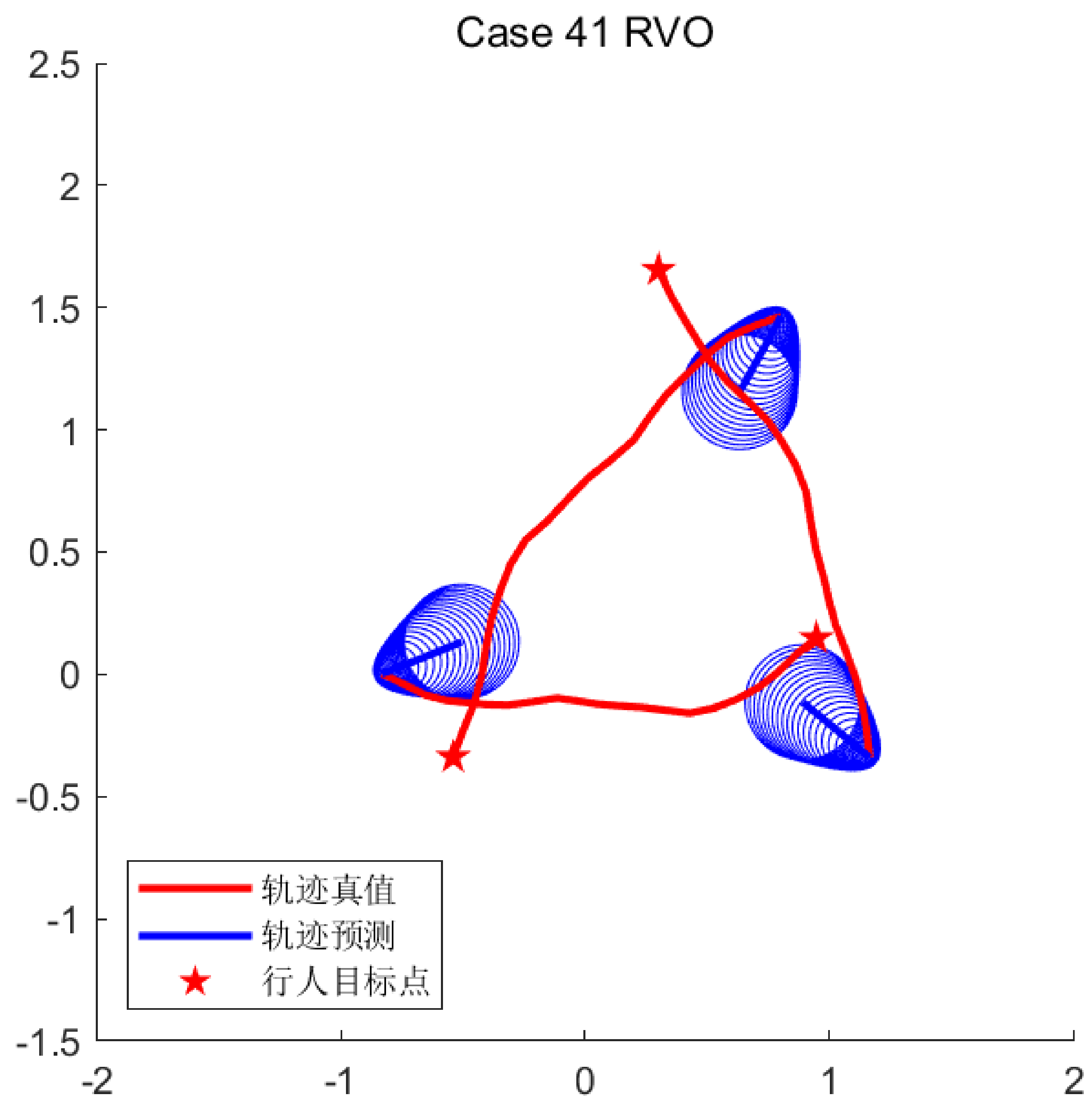
		IPT			CITR		
		ADE[m]	FDE[m]	Time[sec]	ADE[m]	FDE[m]	Time[sec]
RVO[2]		0.3218	0.5457	**0.0001**	0.5067	0.8811	**0.0012**
CADRL[3]		**0.2610**	**0.4212**	0.2436	**0.4385**	**0.8164**	1.4618
MPC-GPred	N=5	**0.3183**	0.5321	**0.00525**	**0.4652**	**0.8791**	**0.0468**
	N=1	0.3264	**0.5071**	0.0007	0.4801	0.8851	0.0022
	N=10	0.3503	0.5392	0.0245	0.4943	0.9103	0.1233
	N=15	0.3799	0.5629	0.0797	0.5136	0.9574	0.3728

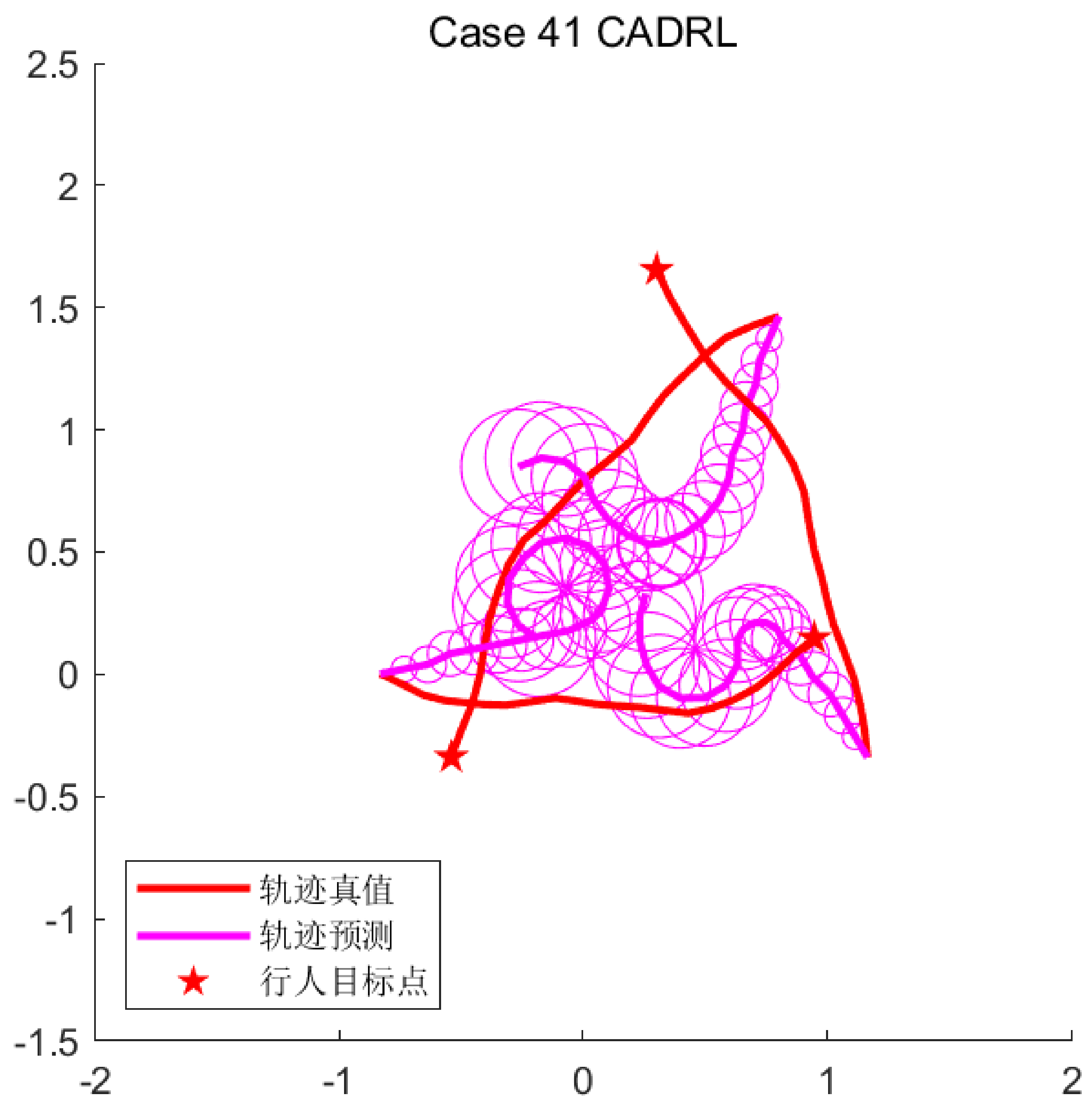
[2] Van den Berg J, Lin M, Manocha D. Reciprocal velocity obstacles for real-time multi-agent navigation[C]//2008 IEEE international conference on robotics and automation. Ieee, 2008: 1928-1935.
[3] Chen Y F, Liu M, Everett M, et al. Decentralized non-communicating multiagent collision avoidance with deep reinforcement learning[C]//2017 IEEE international conference on robotics and automation (ICRA). IEEE, 2017: 285-292.
[4] Rudenko A, Palmieri L, Herman M, et al. Human motion trajectory prediction: A survey[J]. The International Journal of Robotics Research, 2020, 39(8): 895-935.

Pedestrian trajectory prediction experiment

➢IPT Dataset——Intersection

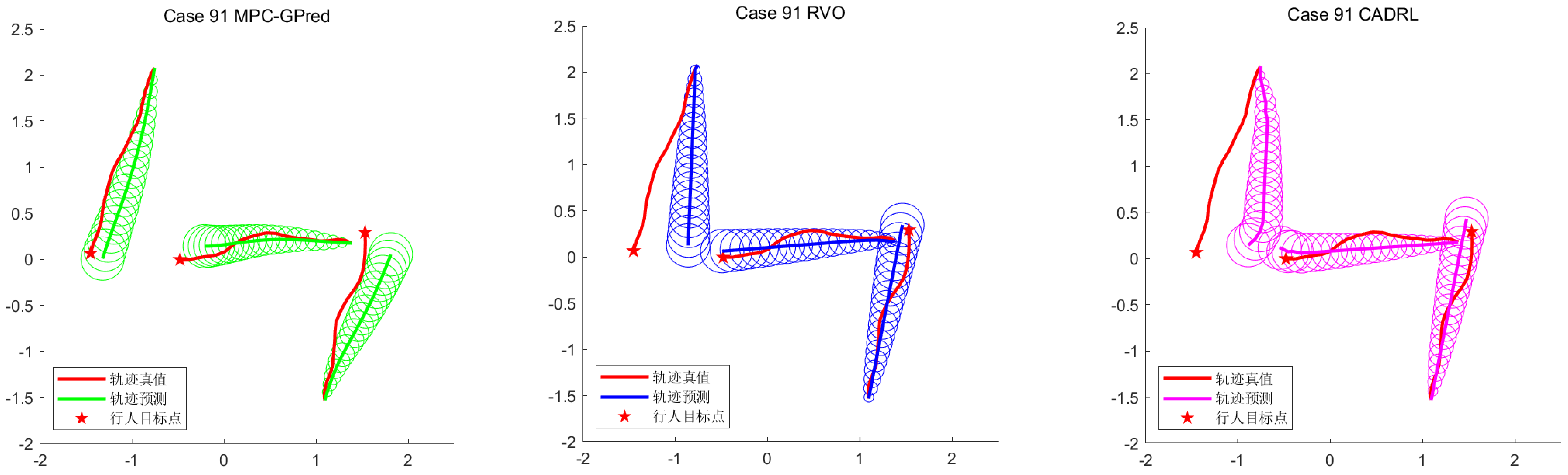






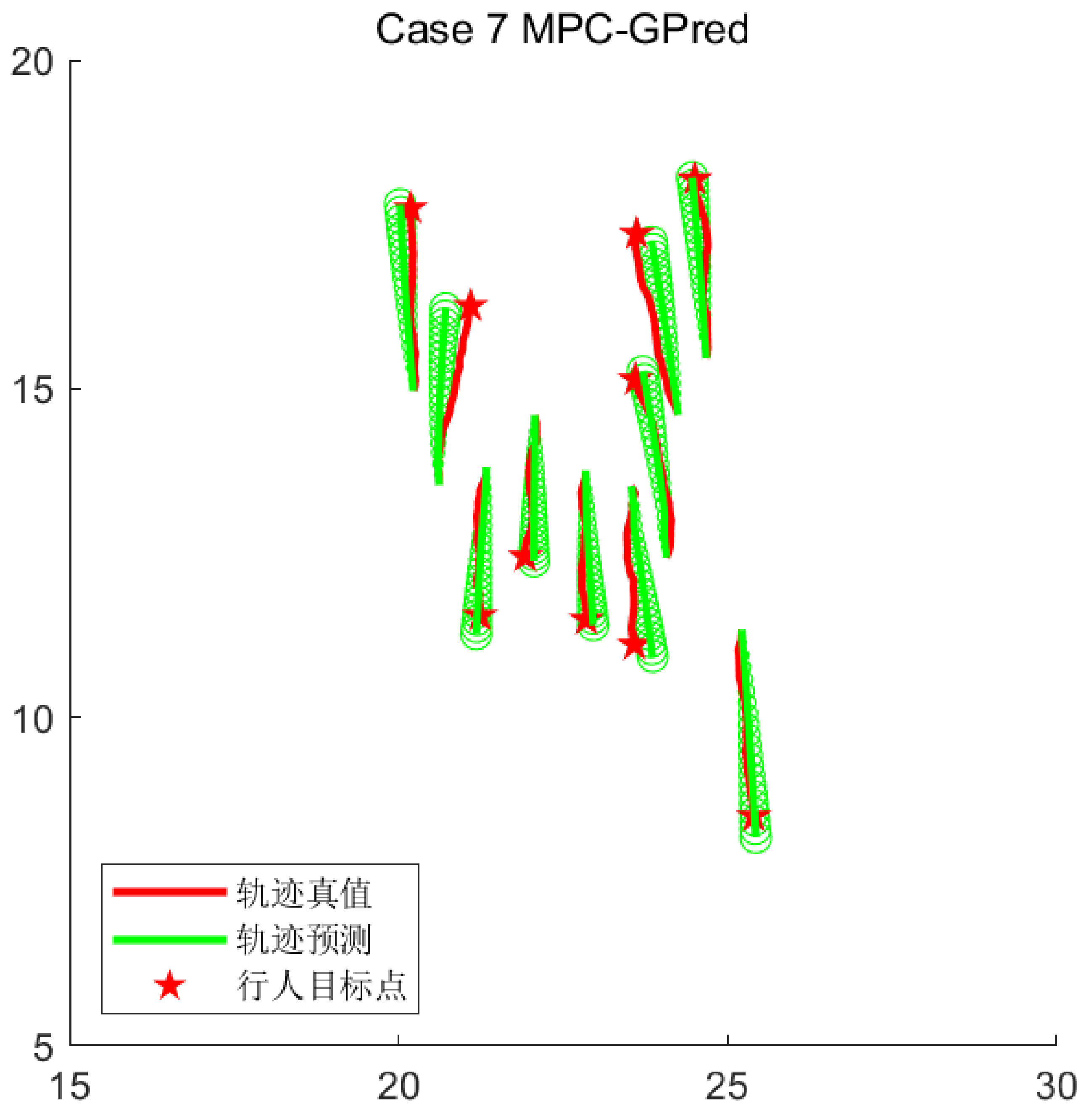
Pedestrian trajectory prediction experiment

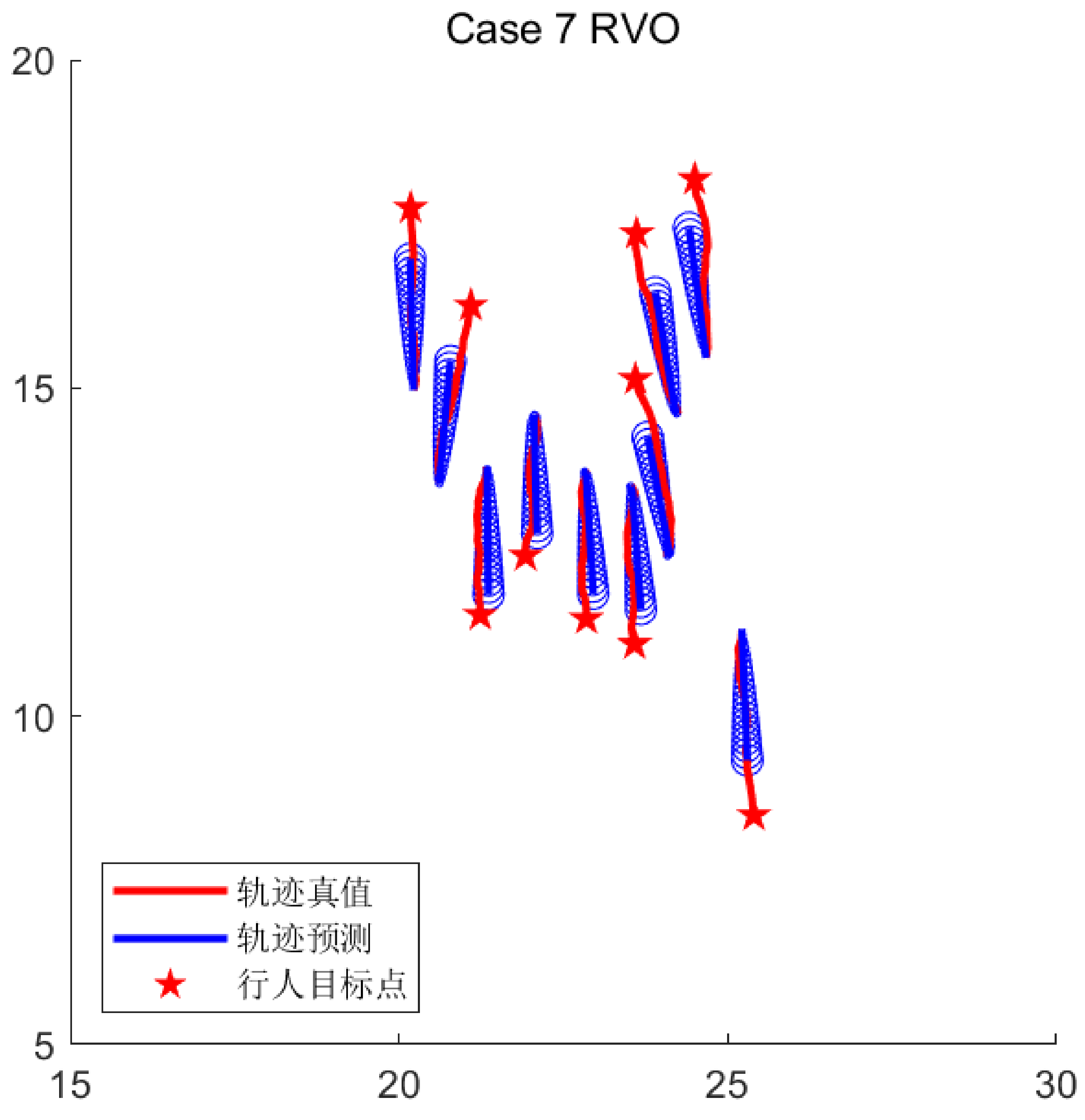
➢IPT Dataset——Crossing

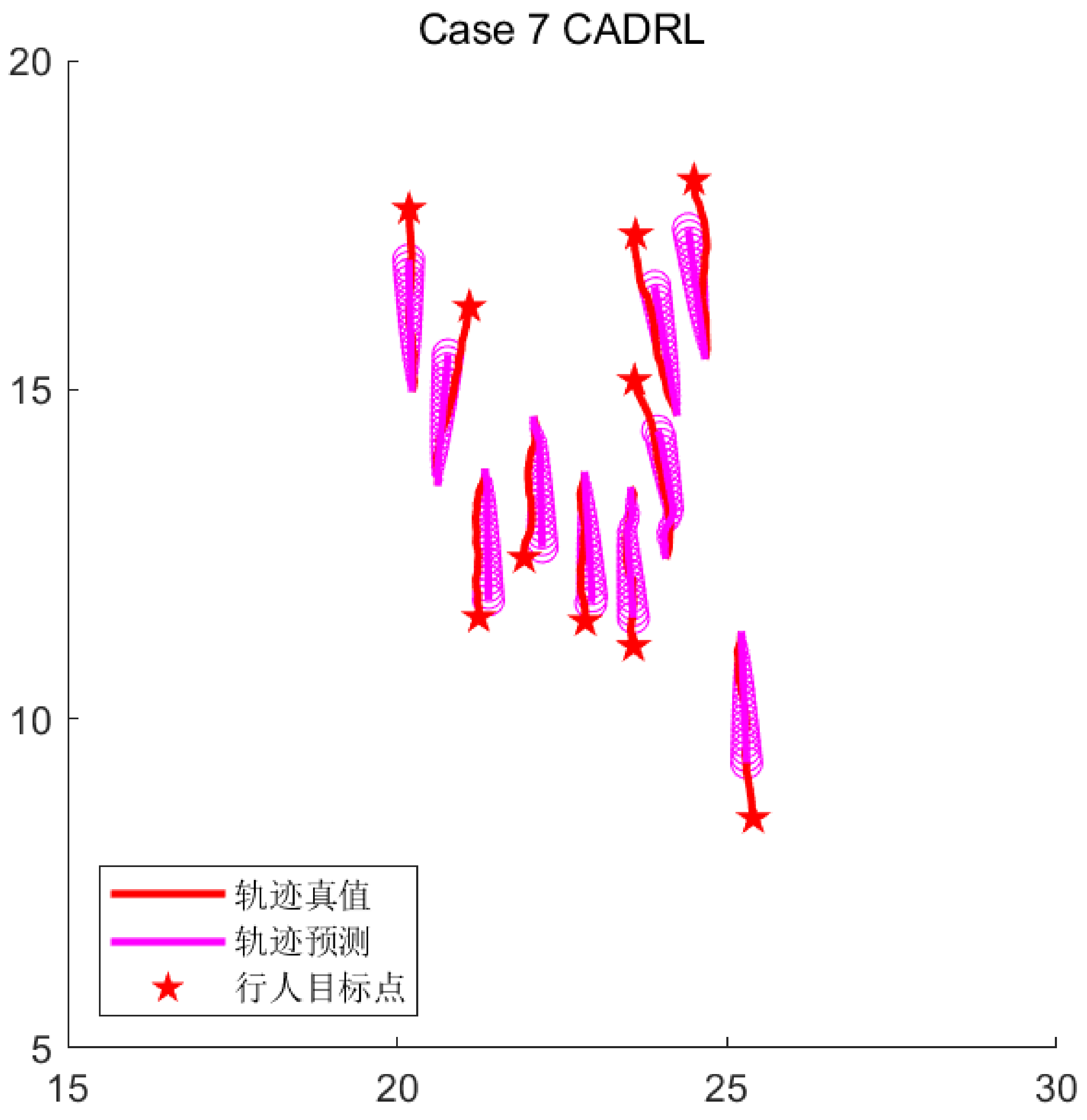


Pedestrian trajectory prediction experiment

➢CITR Dataset——Bidirectional

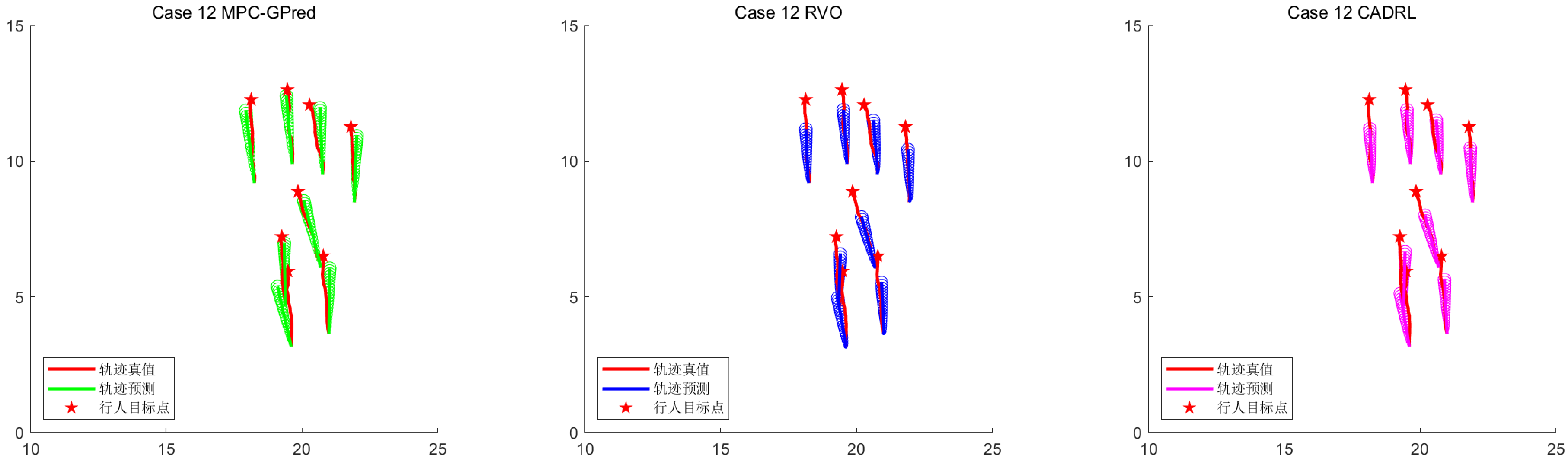






Pedestrian trajectory prediction experiment

➢CITR Dataset——Unidirectional



Simulation for local avoidance

➢Scenario：

6m×6m area with random start(s) and goal(s) generated by MATLAB

➢Scenario：

1 robot v.s. 1/3/5/7 pedestrians $\times 50$

➢Parameter Setting：

$\Delta t = 0.1[sec]$

$N = 5$

➢Strategy Setting

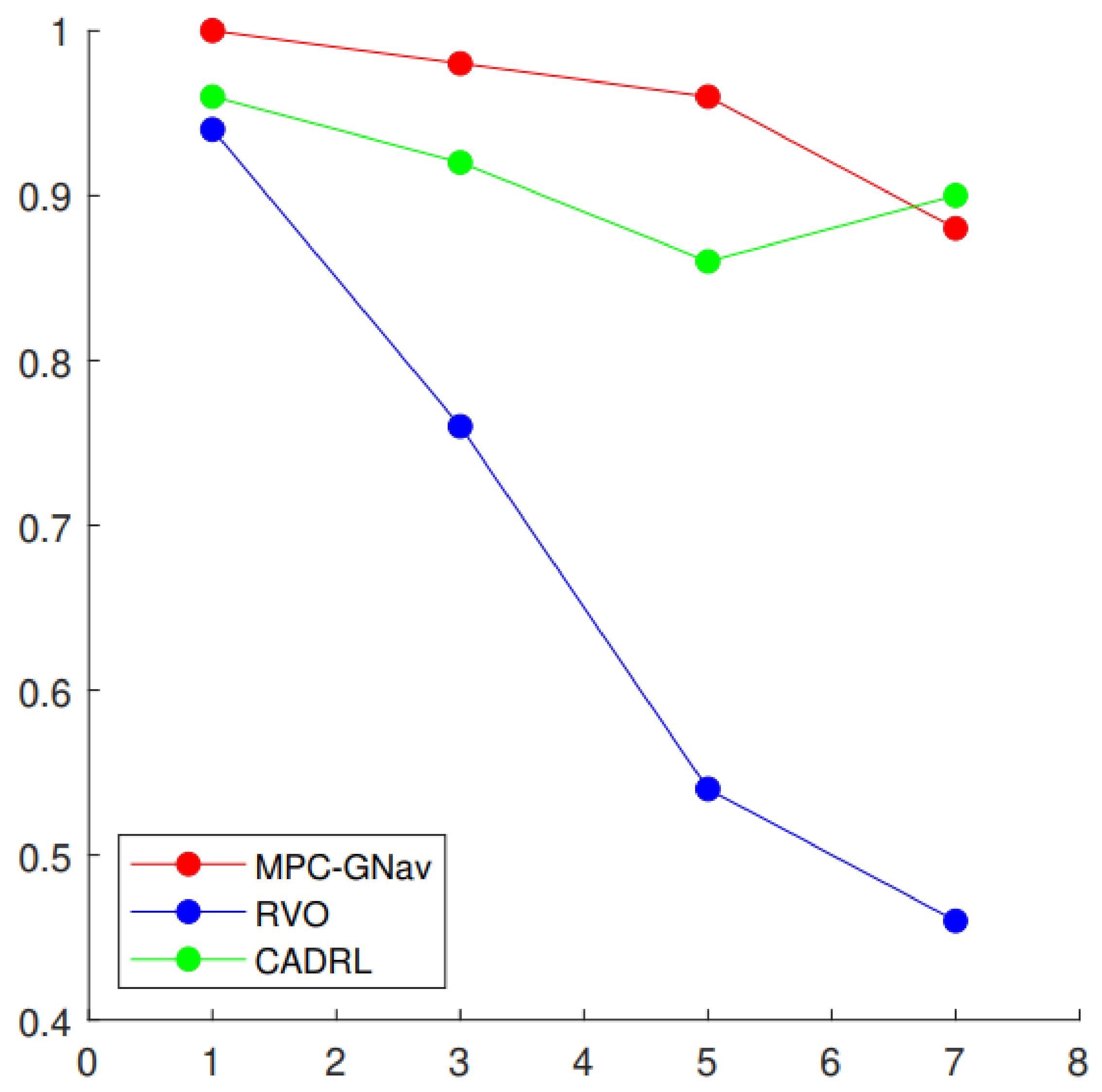
All agents apply the same strategy

➢Evaluation Metric：

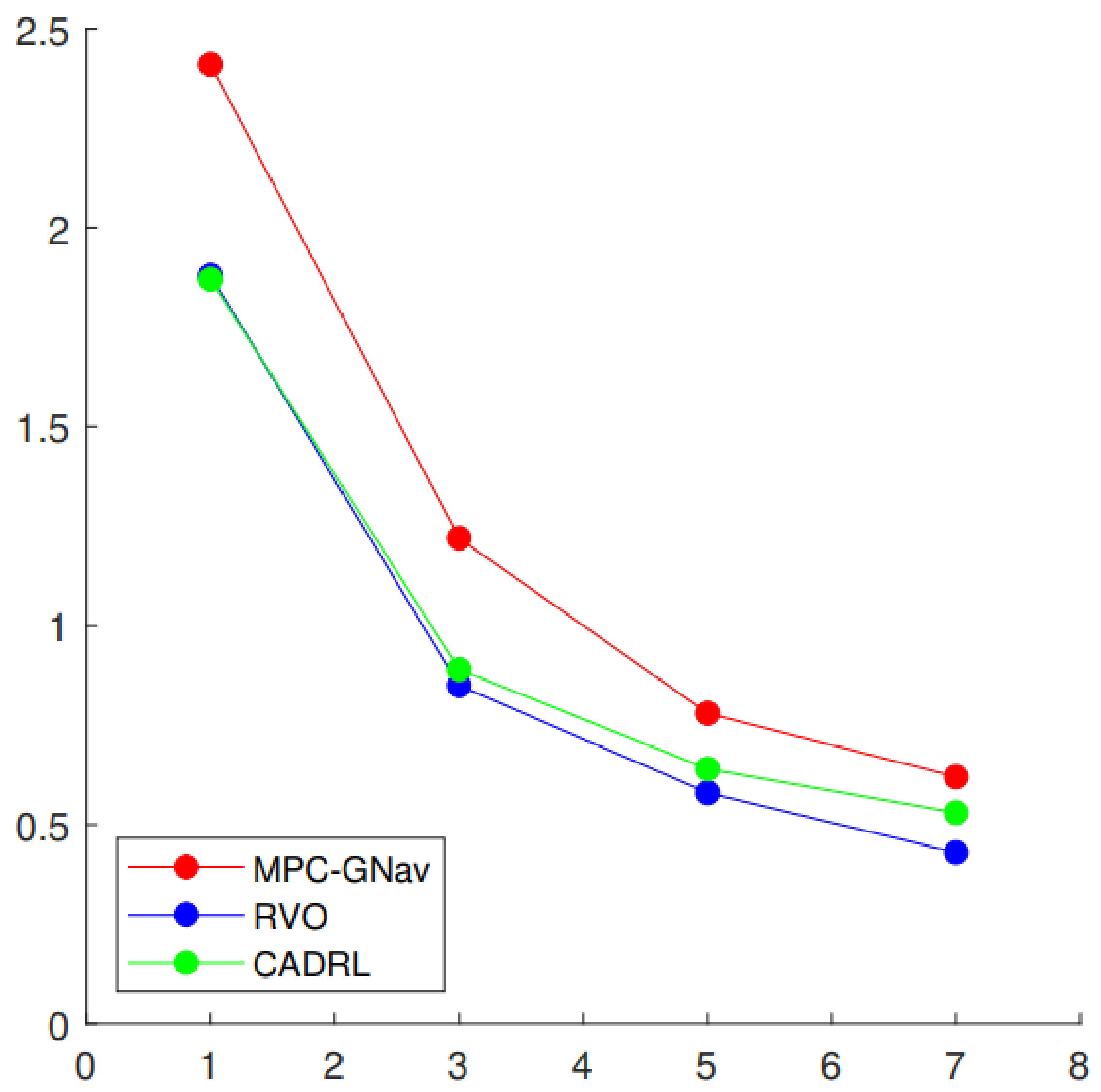
Success Rate

Min. Dist.[m] from other pedestrians

➢Results：



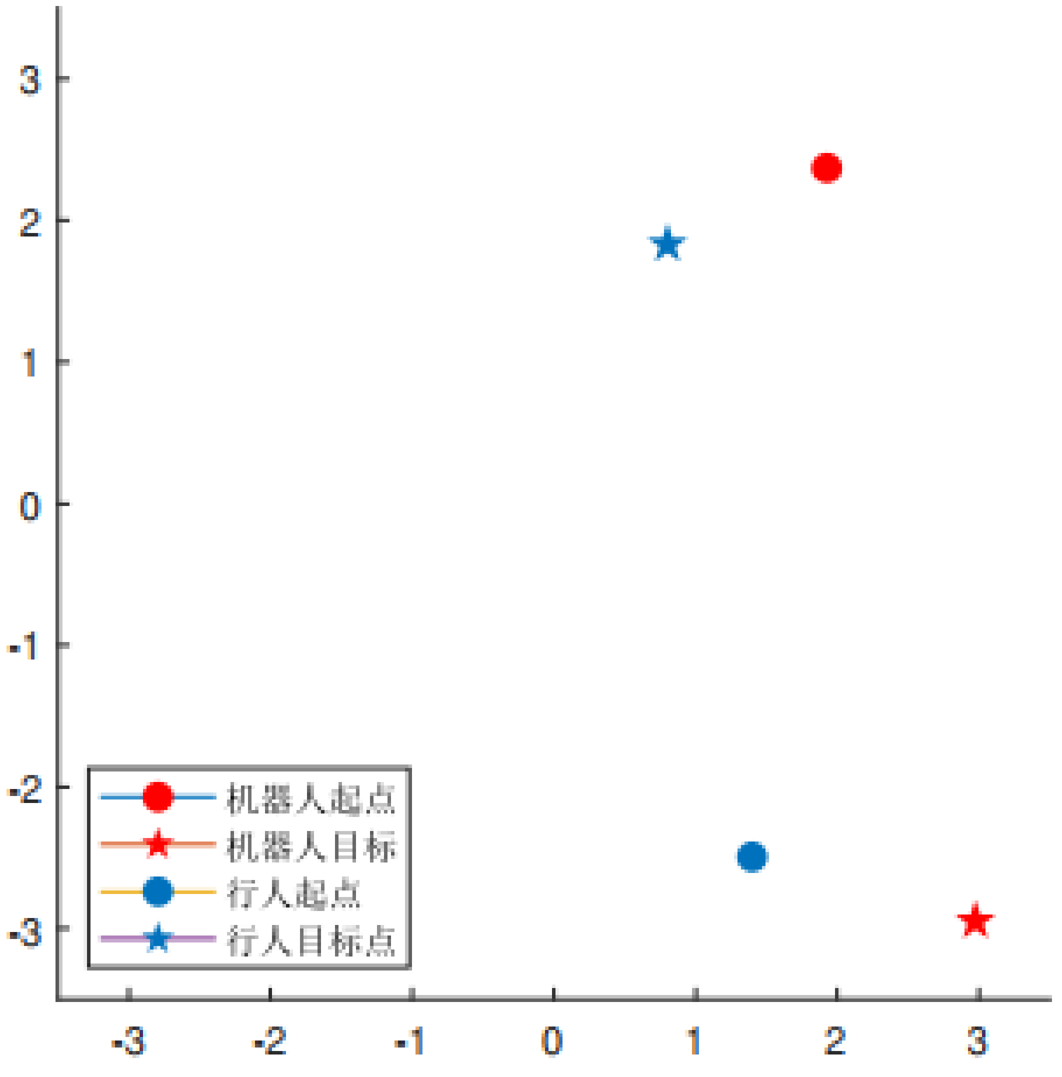
Success rate v.s. No. pedestrian



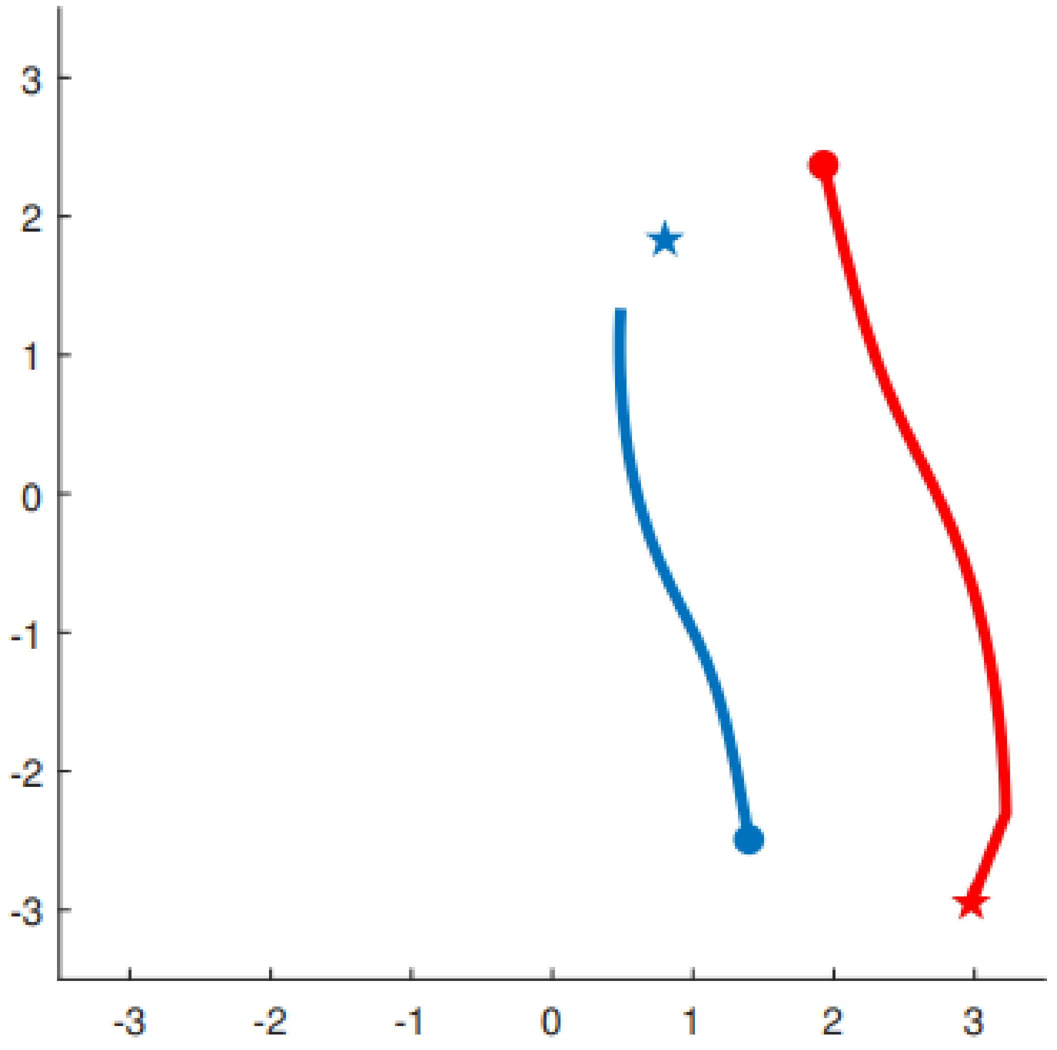
Min. Distance [m] v.s. No. pedestrian

Simulation for local avoidance

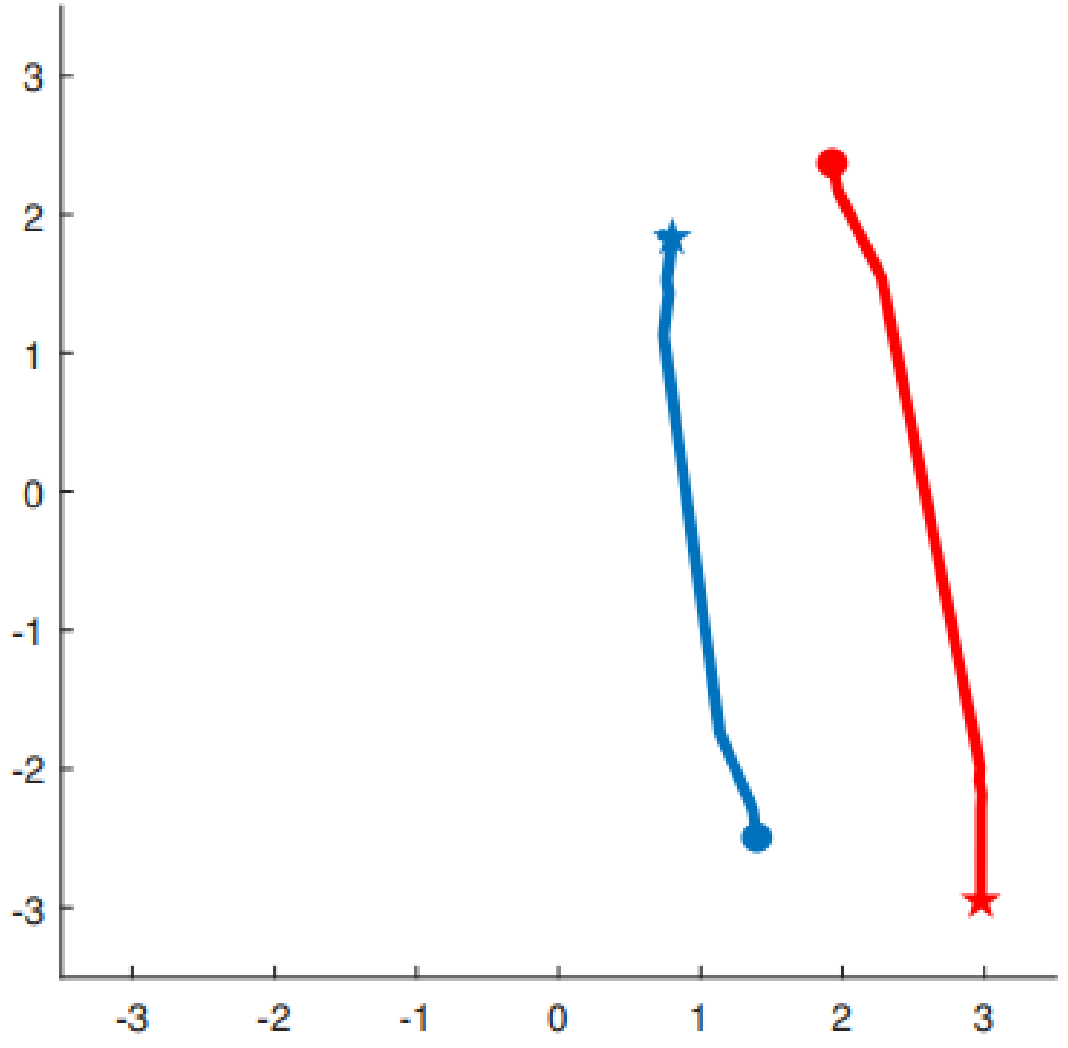
- 1 v.s. 1



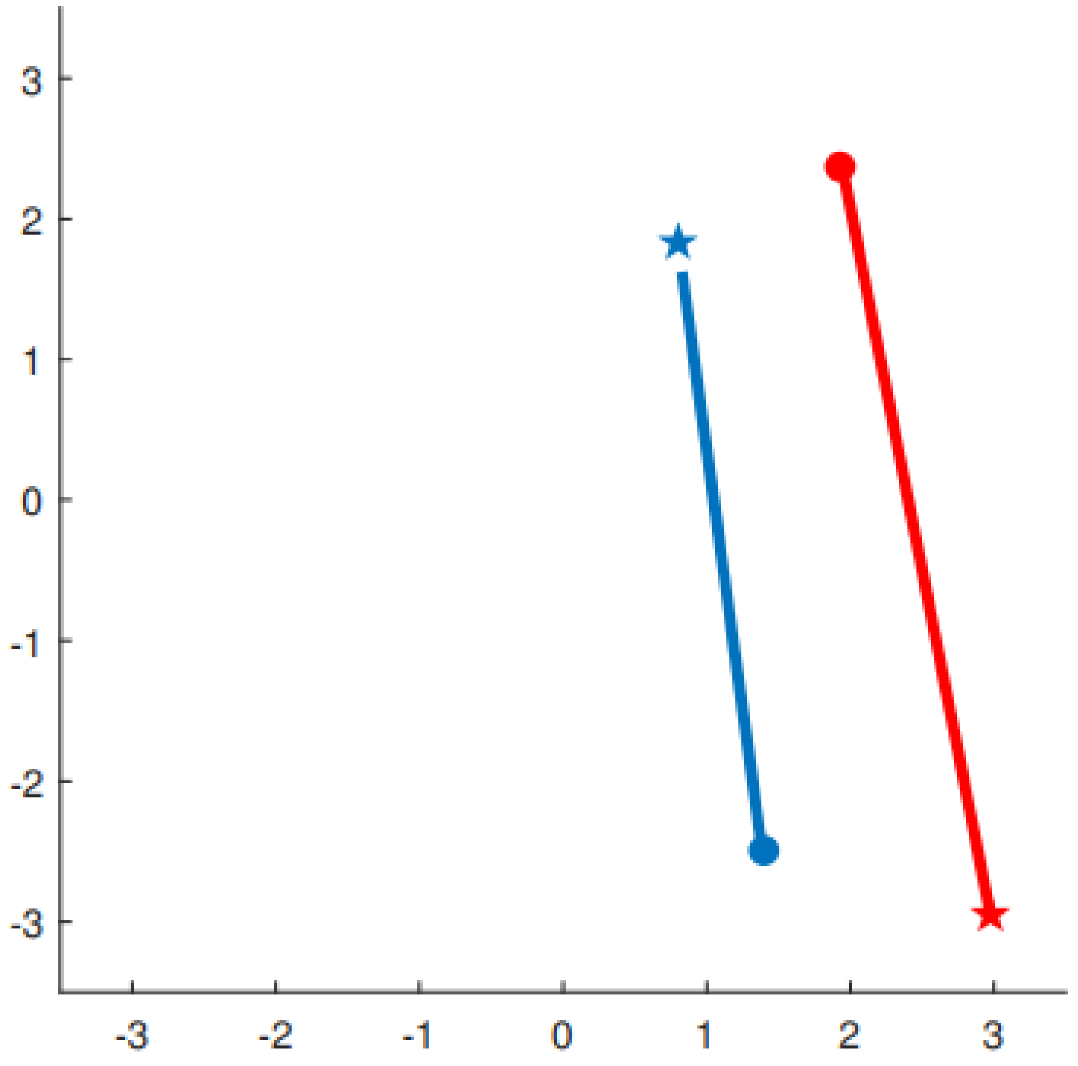
2agents



MPC-GNav Success



CADRL[3] Success

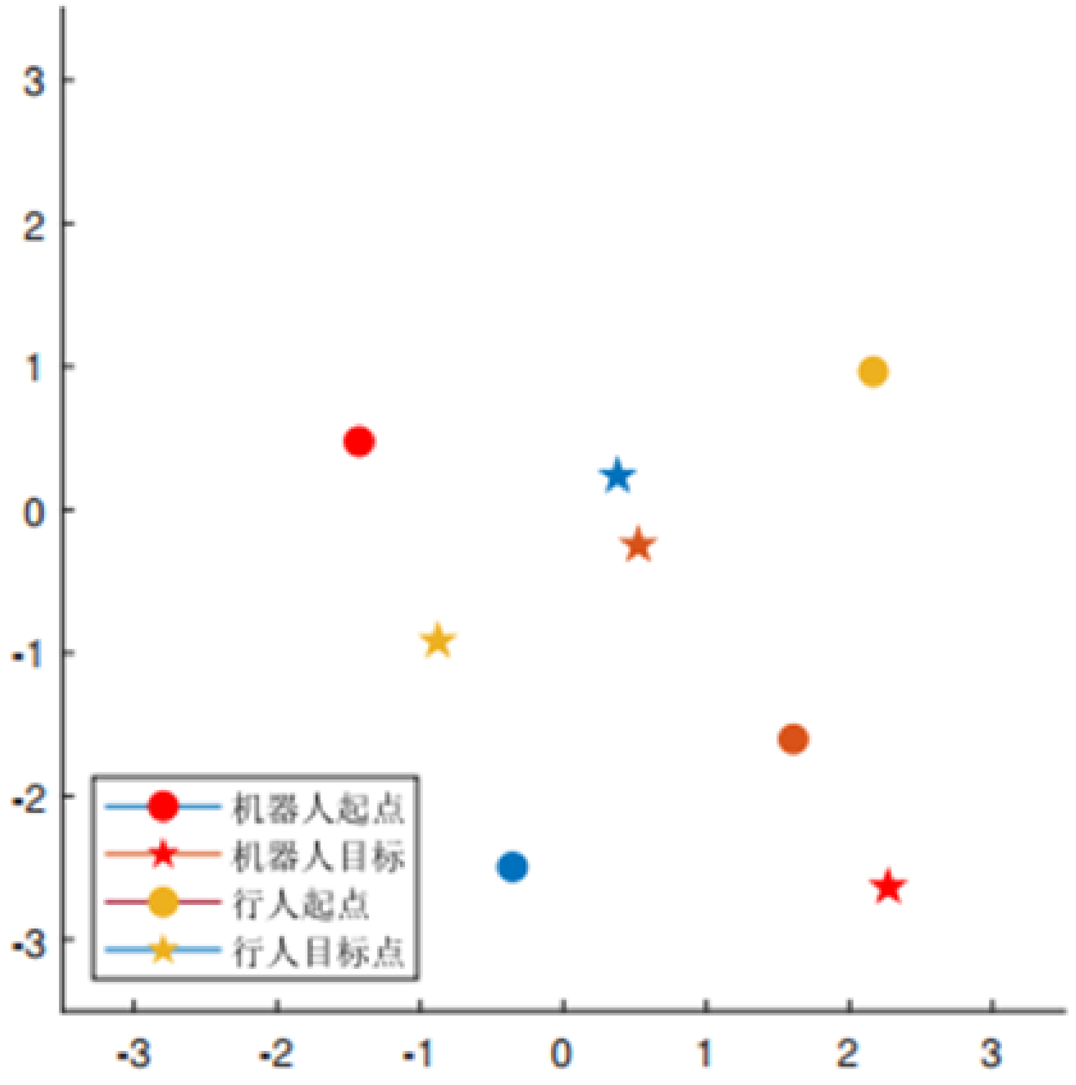


RVO[2] Success

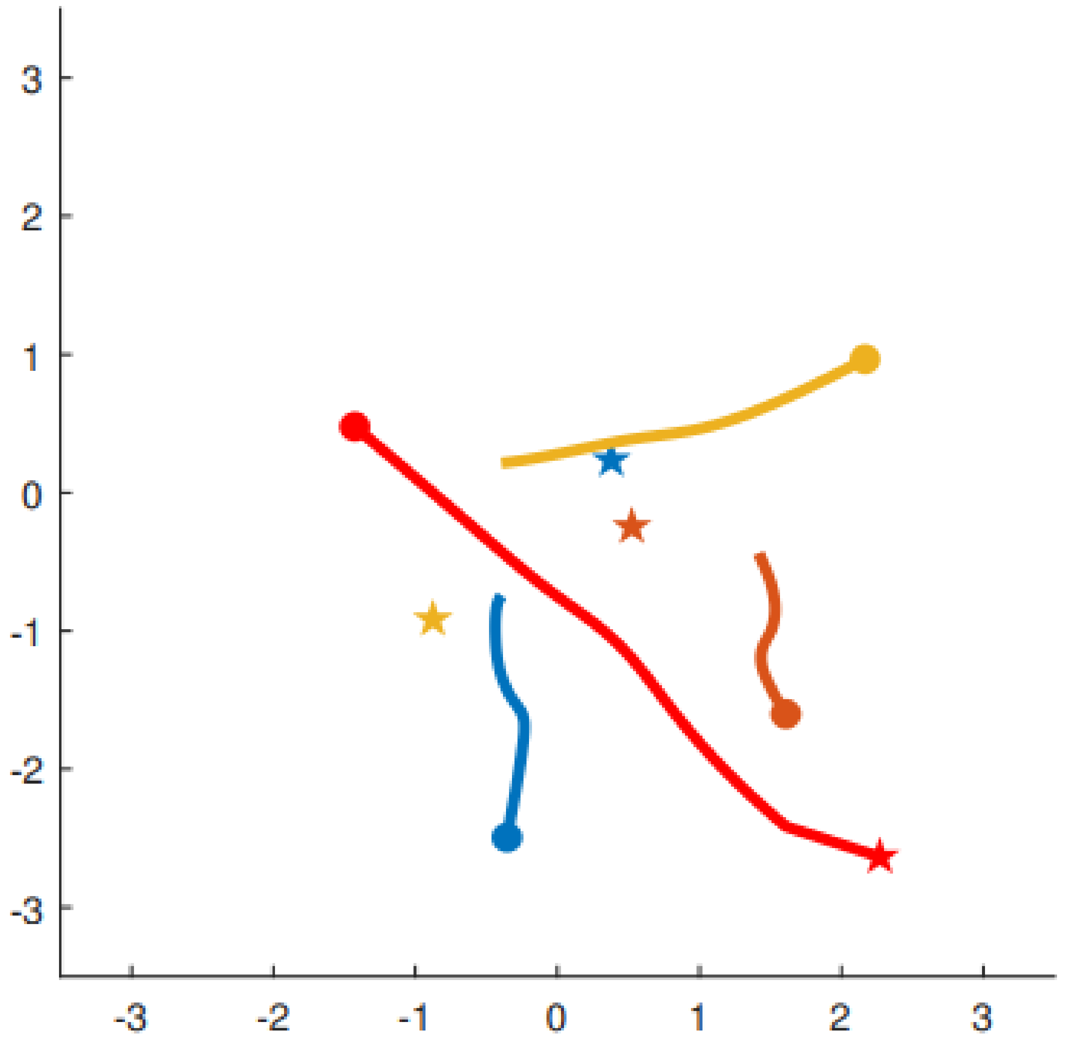
[2] Van den Berg J, Lin M, Manocha D. Reciprocal velocity obstacles for real-time multi-agent navigation[C]//2008 IEEE international conference on robotics and automation. Ieee, 2008: 1928-1935.
[3] Chen Y F, Liu M, Everett M, et al. Decentralized non-communicating multiagent collision avoidance with deep reinforcement learning[C]//2017 IEEE international conference on robotics and automation (ICRA). IEEE, 2017: 285-292.

Simulation for local avoidance

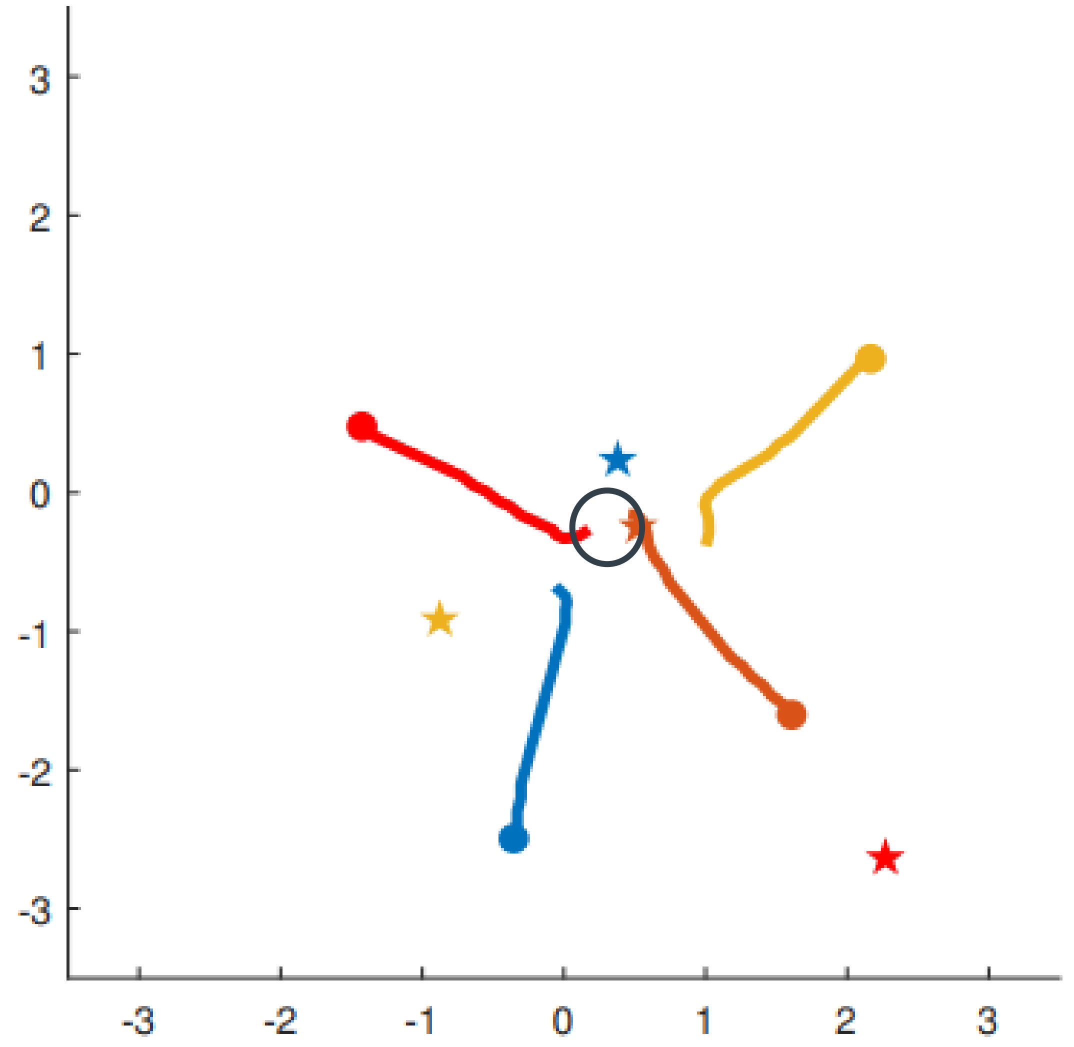
- 1v.s. 3



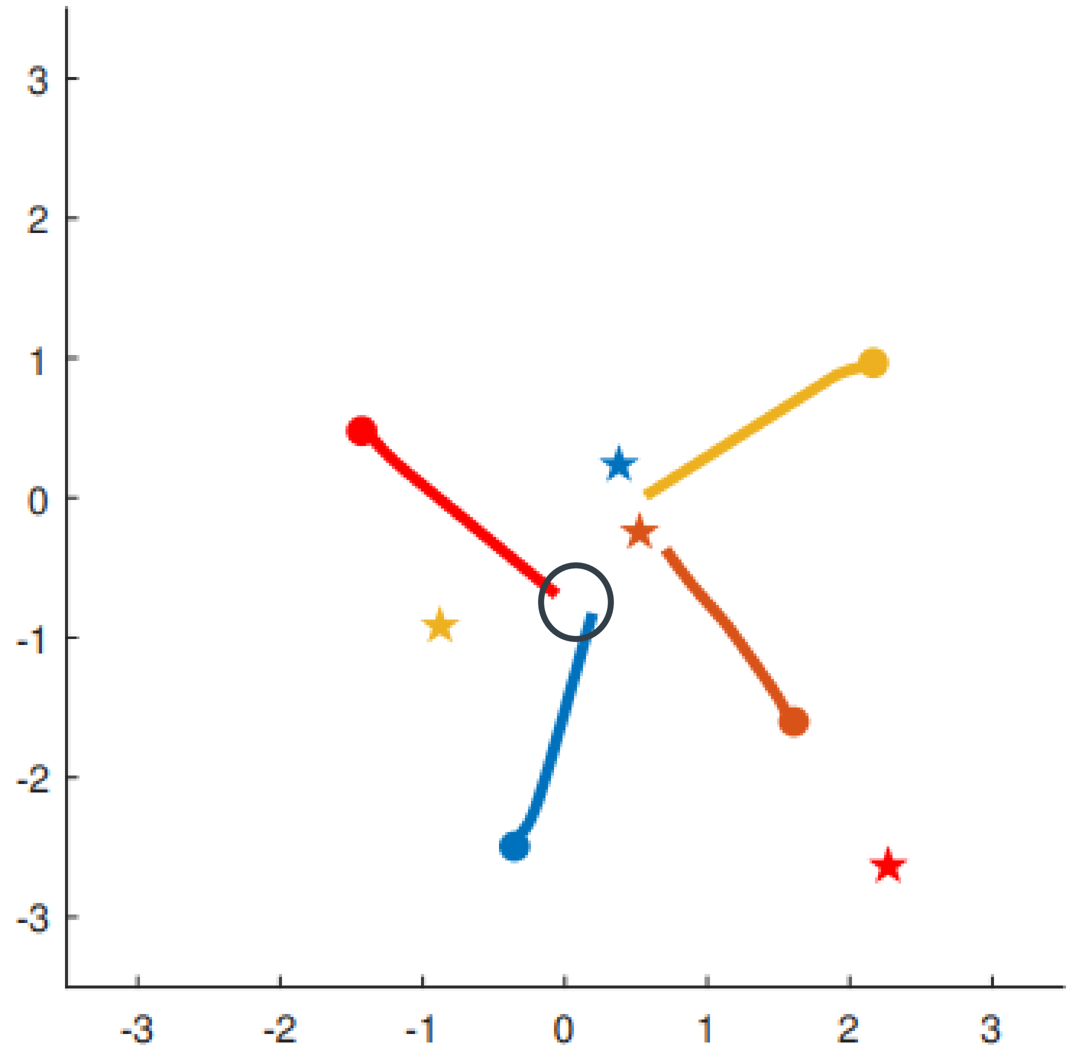
4agents



MPC-GNav Success



CADRL[3] Fail

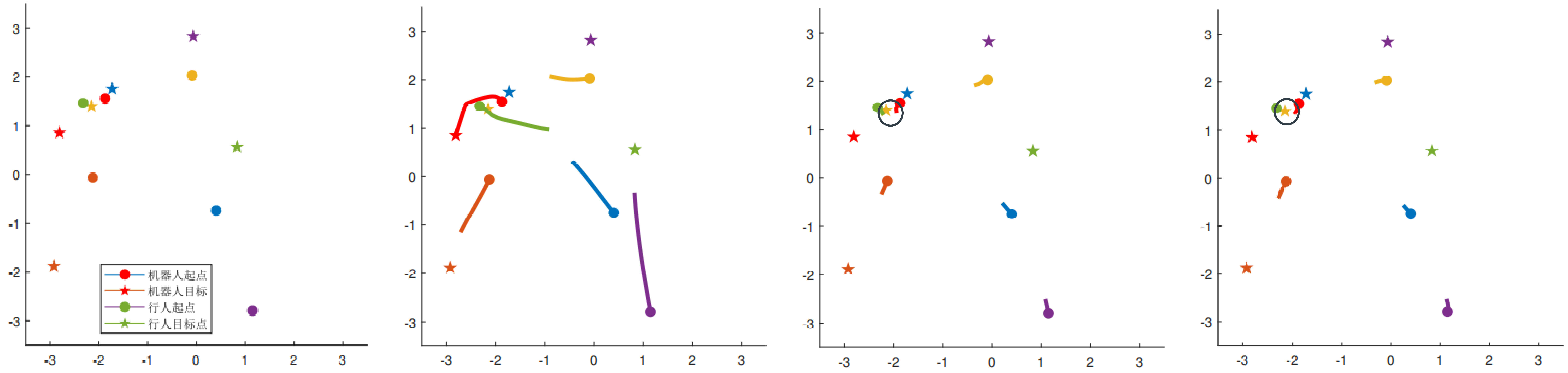


RVO[2] Fail

[2] Van den Berg J, Lin M, Manocha D. Reciprocal velocity obstacles for real-time multi-agent navigation[C]//2008 IEEE international conference on robotics and automation. Ieee, 2008: 1928-1935.
[3] Chen Y F, Liu M, Everett M, et al. Decentralized non-communicating multiagent collision avoidance with deep reinforcement learning[C]//2017 IEEE international conference on robotics and automation (ICRA). IEEE, 2017: 285-292.

Simulation for local avoidance

- 1 v.s. 5

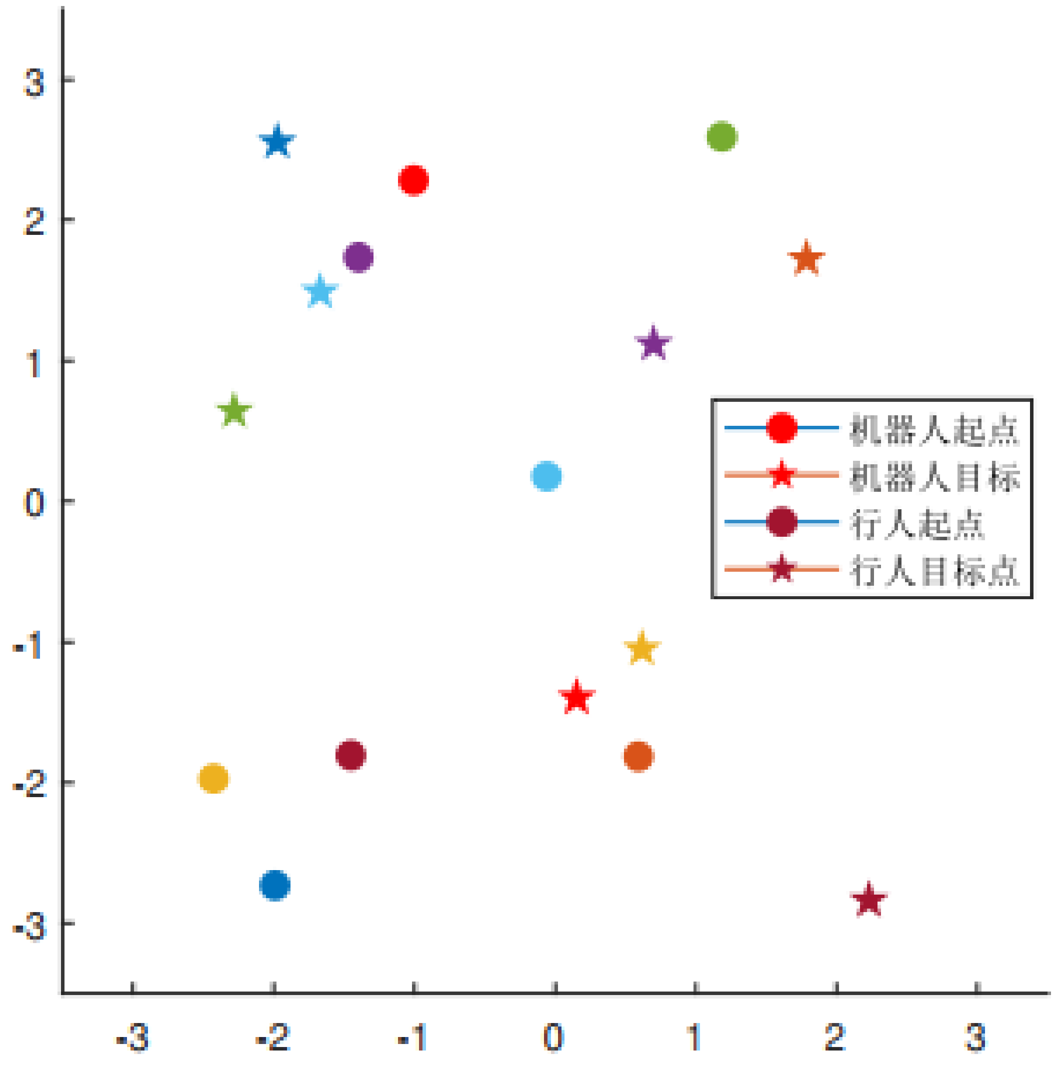


6agents　MPC-GNav Success　CADRL[3] Fail　RVO[2] Fail

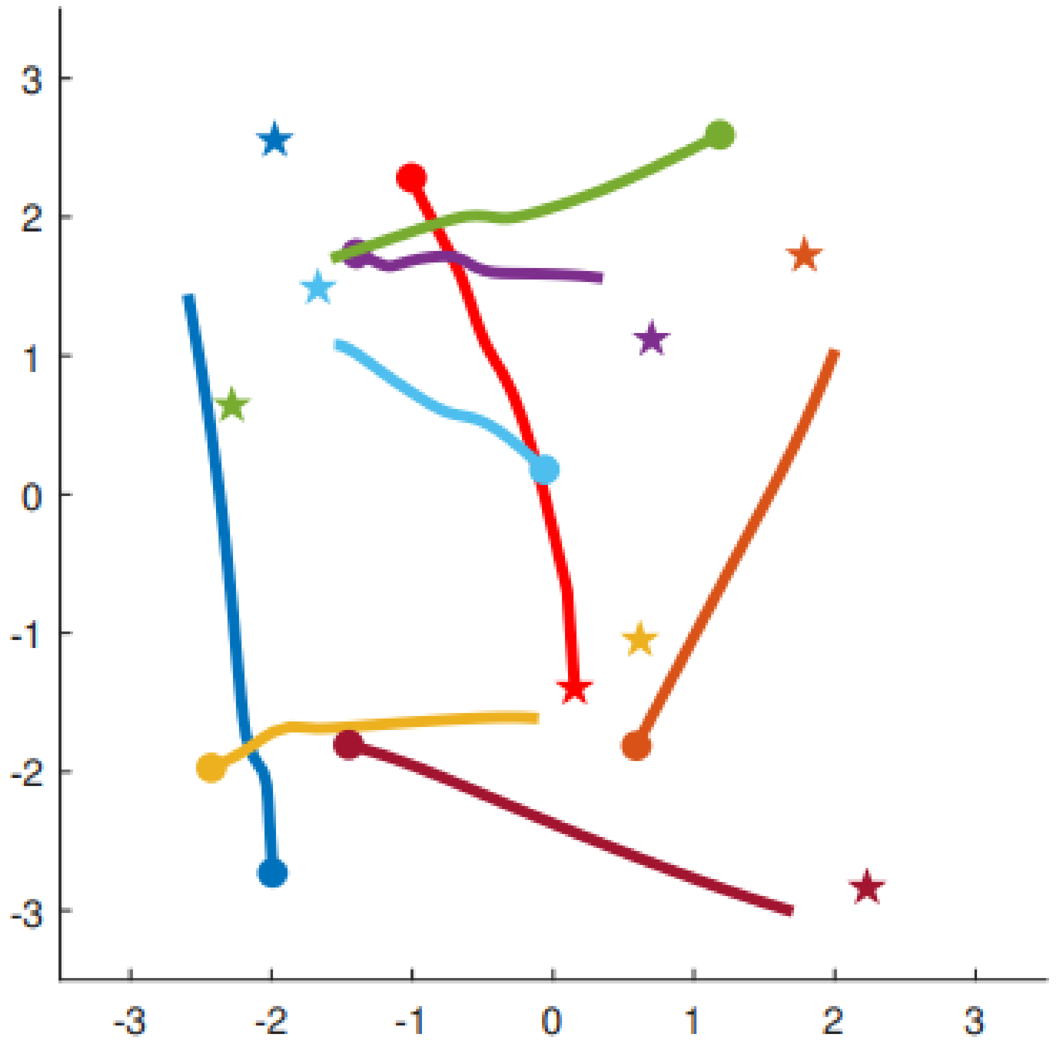
[2] Van den Berg J, Lin M, Manocha D. Reciprocal velocity obstacles for real-time multi-agent navigation[C]//2008 IEEE international conference on robotics and automation. Ieee, 2008: 1928-1935.
[3] Chen Y F, Liu M, Everett M, et al. Decentralized non-communicating multiagent collision avoidance with deep reinforcement learning[C]//2017 IEEE international conference on robotics and automation (ICRA). IEEE, 2017: 285-292.

Simulation for local avoidance

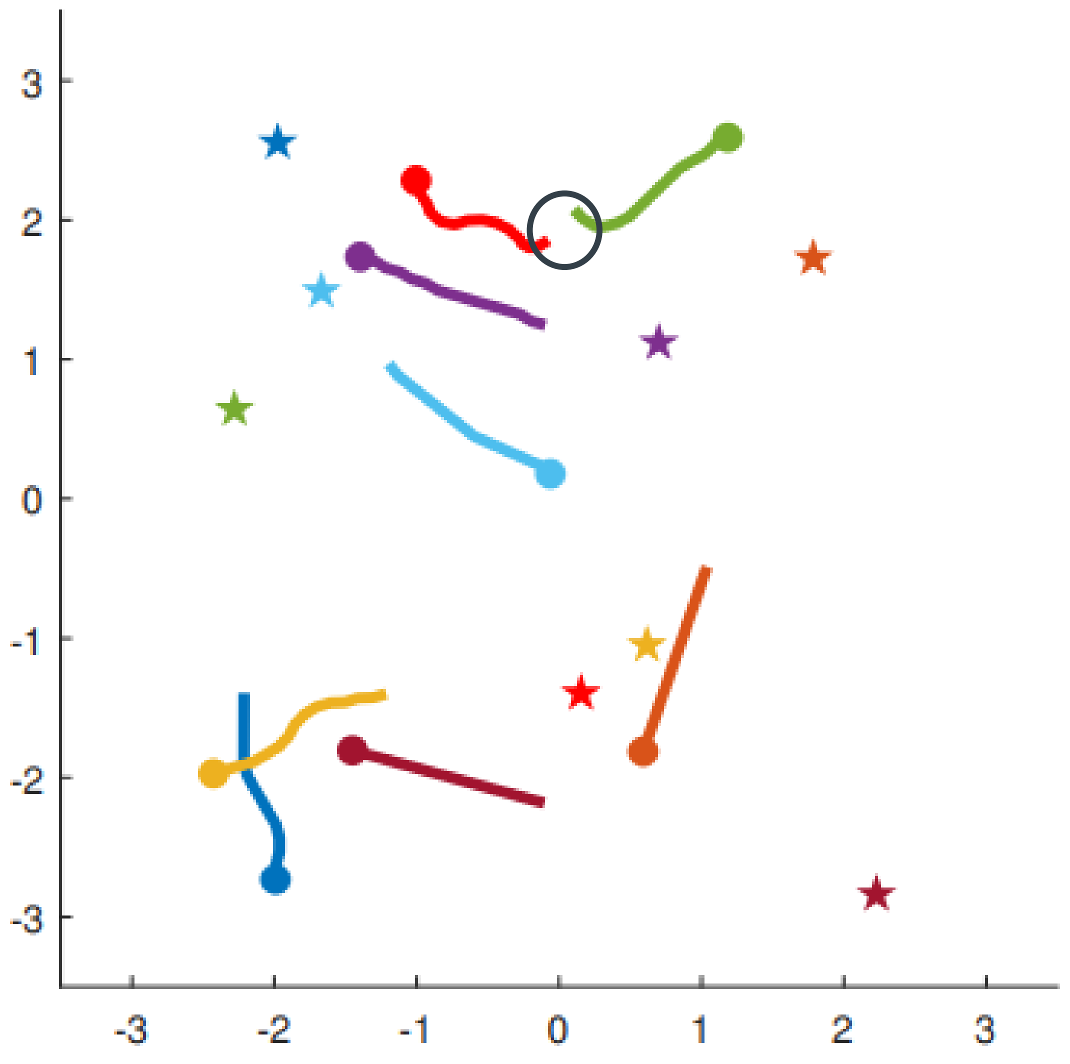
- 1 v.s. 7



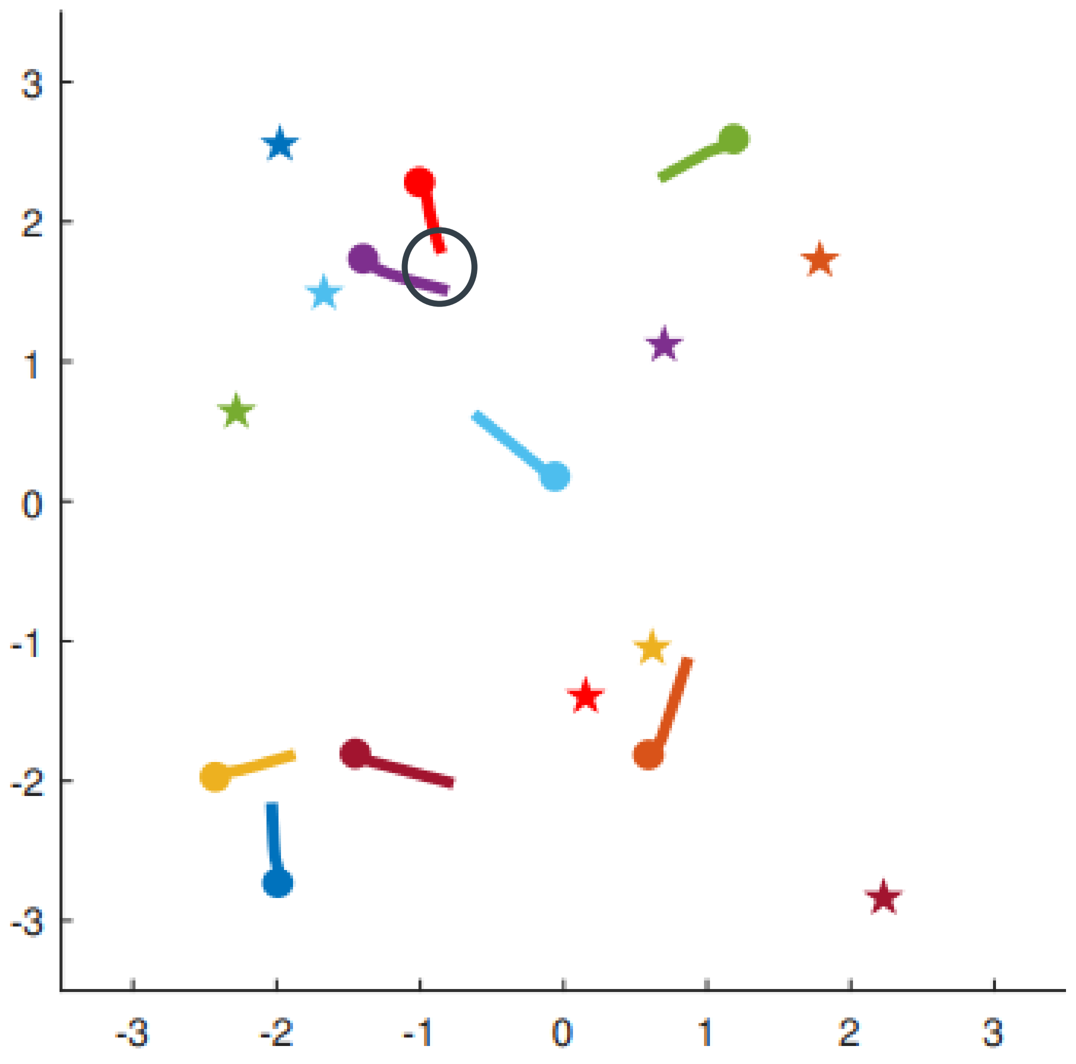
8agents



MPC-GNav Success



CADRL[3] Fail



RVO[2] Fail

[2] Van den Berg J, Lin M, Manocha D. Reciprocal velocity obstacles for real-time multi-agent navigation[C]//2008 IEEE international conference on robotics and automation. Ieee, 2008: 1928-1935.
[3] Chen Y F, Liu M, Everett M, et al. Decentralized non-communicating multiagent collision avoidance with deep reinforcement learning[C]//2017 IEEE international conference on robotics and automation (ICRA). IEEE, 2017: 285-292.

Experiment Video

Conclusion

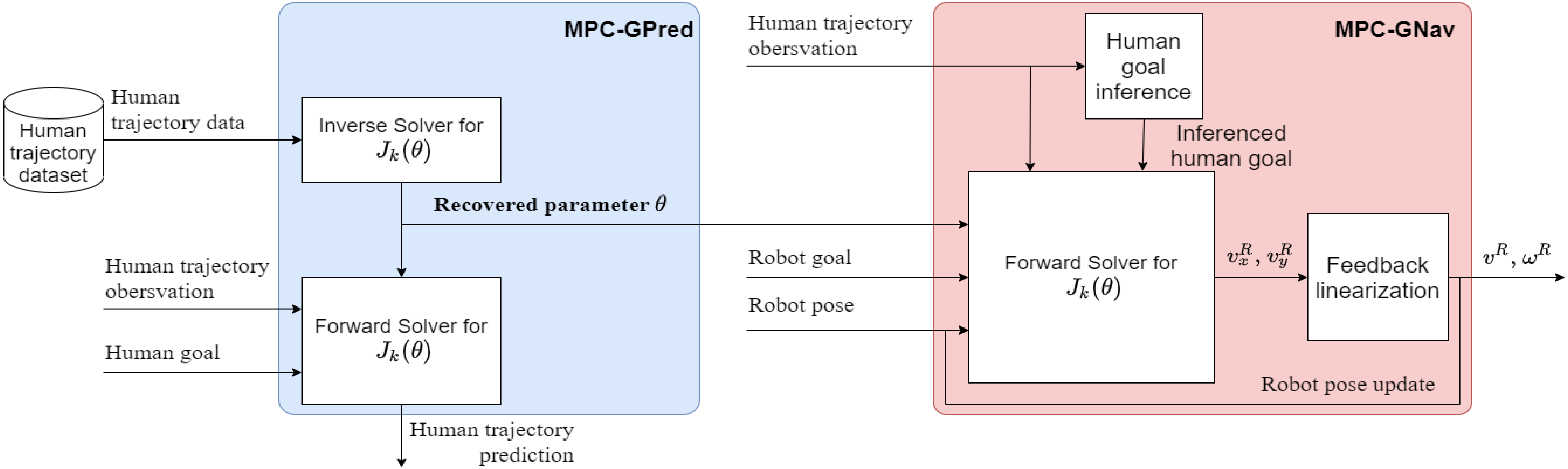
- Conclusion
  - MPC-GPred

Accuracy & time efficiency in pedestrian trajectory prediction

  - MPC-GNav

Safeness & time efficiency in robot social navigation

- Prospects
  - Better goal inference techniques
  - Better pedestrian tracking techniques
  - New objective functions & solvers



Overall Framework

References

[1] Yang D, Li L, Redmill K, et al. Top-view trajectories: A pedestrian dataset of vehicle-crowd interaction from controlled experiments and crowded campus[C]//2019 IEEE Intelligent Vehicles Symposium (IV). IEEE, 2019: 899-904.

[2] Chen Y F, Liu M, Everett M, et al. Decentralized non-communicating multiagent collision avoidance with deep reinforcement learning[C]//2017 IEEE international conference on robotics and automation (ICRA). IEEE, 2017: 285-292.

[3] D. Fridovich-Keil, E. Ratner, L. Peters, A. D. Dragan and C. J. Tomlin, "Efficient Iterative Linear-Quadratic Approximations for Nonlinear Multi-Player General-Sum Differential Games," 2020 IEEE International Conference on Robotics and Automation (ICRA), 2020, pp. 1475-1481, doi: 10.1109/ICRA40945.2020.9197129.

[4] Rudenko A, Palmieri L, Herman M, et al. Human motion trajectory prediction: A survey[J]. The International Journal of Robotics Research, 2020, 39(8): 895-935.

[5] Jia, Dan, Alexander Hermans, and Bastian Leibe. "DR-SPAAM: A spatial-attention and auto-regressive model for person detection in 2D range data." 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, 2020.

MY BIO

THANK YOU.

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