Autonomous Human-aware Navigation in Dense Crowds

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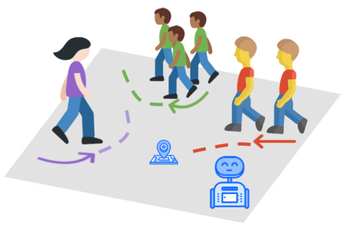
Introduction

Motivation: Navigate Like Human

70% of humans tend to form interactive groups in social environments[1].
Can robots learn to follow certain pedestrian etiquette to navigate based on its understanding of social interactions among pedestrians?



Problem Definition

Given trajectories of observed pedestrians $\boldsymbol{X} = X_1, X_2, ..., X_n$ and the target agent's goal g_i, predict the future trajectory $\hat{Y}_i$ of the target agent i. The input trajectory of an agent j is defined as $X_j = (x_j^t, y_j^t)$ from time steps $t = 1, ..., t_{obs}$ and the future trajectory (ground truth) as $Y_j = (x_j^t, y_j^t)$ from time steps $t = t_{obs} + 1, ..., t_{pred}$.

Definition of Socially Compliant Behaviors[2]

- **Comfort** is the absence of annoyance and stress for humans in interaction with robots
- **Naturalness** is the similarity between robots and humans in low level behavior patterns
- **Sociability** is the adherence to explicit high-level cultural conventions

Our Contribution

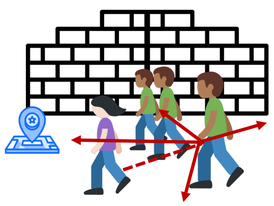
- A socially-aware path planning model based on Social-GAN[3], leveraging public trajectory-prediction dataset
- A physical robot platform covers both the **comfort** and **naturalness** aspects

Method

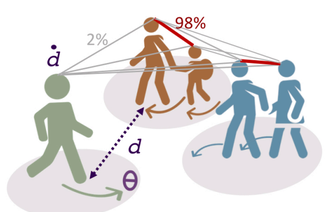
Understand pedestrians by extended SFM[1]

$$\frac{d\vec{v_i}}{dt} = \vec{f_i}^{0} + \vec{f_i}^{wall} + \sum_j \vec{f_{ij}} + \vec{f_i}^{group}$$

$$\vec{f_i}^{group} = \vec{f_i}^{vis} + \vec{f_i}^{att} + \vec{f_i}^{rep}$$



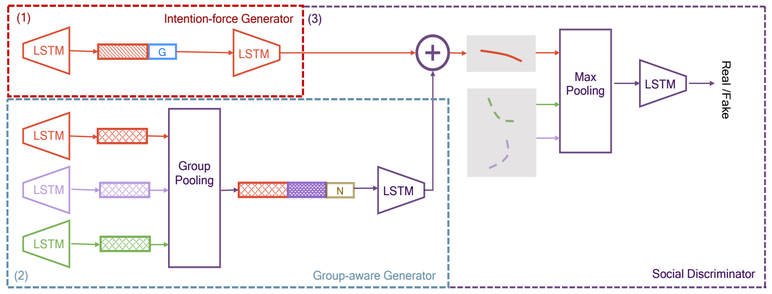
Infer social relationship through coherent motion indicators



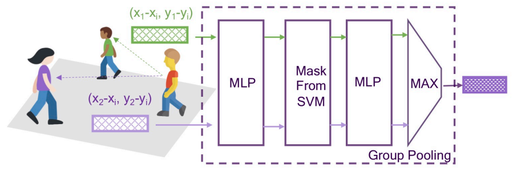
Coherent motion indicators → SVM [7] → Group Probability

Jointly optimize naturalness and comfort from trajectory prediction

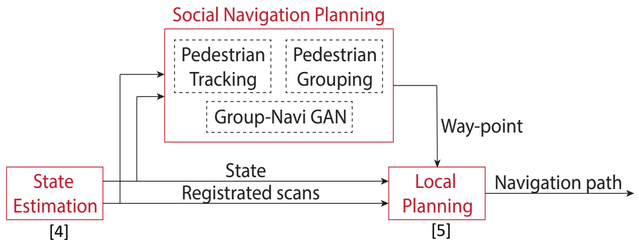
- Intention-force generator: Driving force towards the goal
- Group-aware generator: Aggregate interaction force from other agents
- Social discriminator: classification on social acceptability



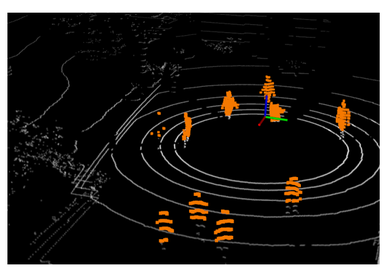
Consider group interactions from pedestrians with similar social relations



System Overview



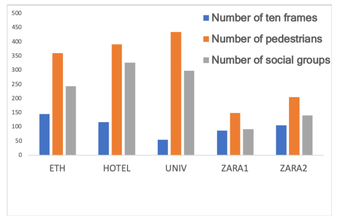
Segment pedestrians from the prior map in point cloud



Results

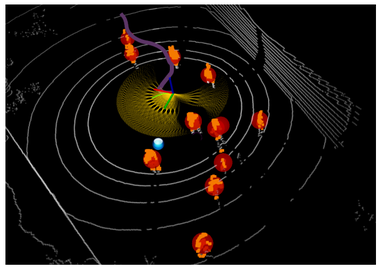
Improve trajectory prediction accuracy

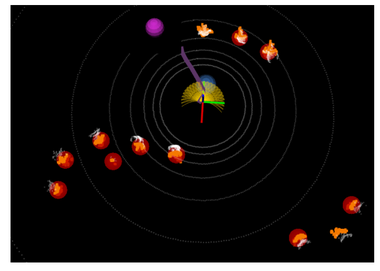
Metric	Dataset	Linear	SGAN[3]	Navi-GAN[6]	Group-Navi-GAN
ADE	ETH	0.84	**0.60**	0.95	1.33
	HOTEL	**0.35**	0.48	0.43	0.39
	UNIV	0.56	0.36	0.85	**0.29**
	ZARA1	0.41	0.21	0.40	**0.21**
	ZARA2	0.53	**0.27**	0.47	0.30
AVG		0.54	0.39	0.62	0.50
FDE	ETH	1.60	**1.22**	1.64	1.98
	HOTEL	**0.60**	0.95	0.74	0.93
	UNIV	1.01	0.75	1.36	**0.68**
	ZARA1	0.74	0.42	0.66	**0.40**
	ZARA2	0.95	**0.54**	0.72	0.85
AVG		0.98	0.78	1.02	0.96



*ADE: average displacement error(meters); FDE: final displacement error(meters)

Demonstrate group following behaviors in simulations

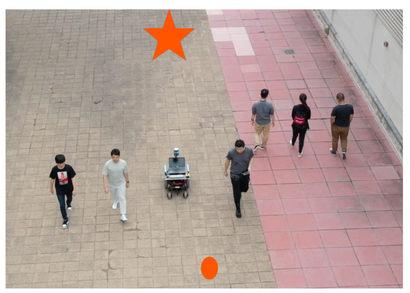


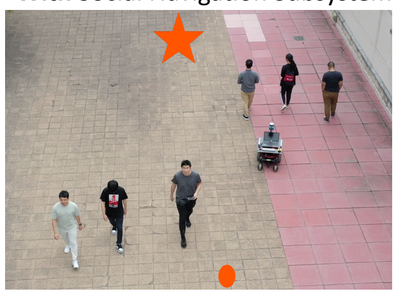


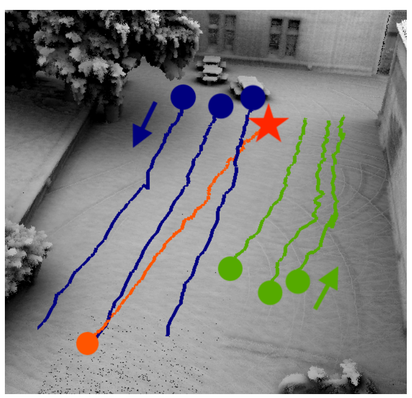
Autonomous navigation results in dense crowds. The coordinate frame indicates the robot. The white points are registered laser scans. The red dots are tracked pedestrians. The yellow paths are collision-free paths from the local planning subsystem. The blue dot is the way-point from the social navigation subsystem. The purple curve shows the trajectory of the vehicle.

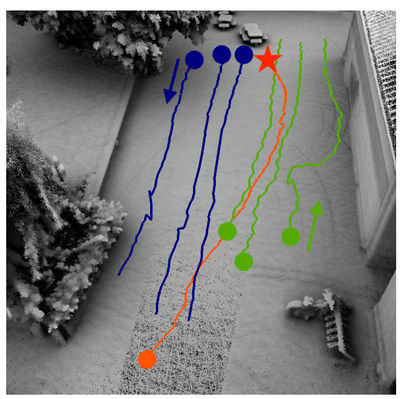
Conduct real-world experiments with a robot vehicle

Without Social Navigation Subsystem **With** Social Navigation Subsystem









Start point of the robot
Goal point of the robot
Start points of pedestrians from two groups
Heading directions of pedestrians from two groups

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