Ablation Study Configurations and Results

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1 Configurations

Configurations of ablation study. PG+P and SG+P are not included in the manuscript since they only provide minor comparisons. A standard feedback and feedforward tracking controller is used to follow the time-varying trajectory. Let $g_R^W(t)$ be the current robot pose in the world frame and $g_R^{W,*}$ be the desired robot pose in the world frame. Define the pose error by

$$g_{\text{err}} = (g_R^W(t))^{-1} g_R^{W,*} \tag{1}$$

Extract from g_{err} the x-coordinate error Δx, y-coordinate error Δy, and the orientation error $\Delta\theta$. The commanded robot body velocity for nonholonomic robots is

$$\xi_{\text{com}} = \begin{bmatrix} \nu \\ \omega \end{bmatrix} = \begin{bmatrix} k_{\text{drive,x}} & 0 & 0 \\ 0 & k_{\text{drive,y}} & k_{\text{turn}} \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta y \\ \Delta\theta \end{bmatrix} + \begin{bmatrix} \nu^*(t) \\ \omega^*(t) \end{bmatrix} \tag{2}$$

In the PG$^-$, PG, PG+PO, SG$^-$, and SG, there is no desired velocities $[\nu^*(t), \omega^*(t)]^T$ in the feedback controller.

Table 1: Configurations of all planners in the ablation study

Planners	Path Planning	Feedback Tuning	Projection Operator*	Trajectory Synthesis†	Tracking Method
PG$^-$	P	N	N	N	PT
PG	P	Y	N	N	PT
PG+PO	P	Y	Y	N	PT
SG$^-$	B	N	N	N	PT
SG	B	Y	N	N	PT
PG+P	P	N	N	Y	PT
SG+P	B	N	N	Y	PT
PG+M	P	N	N	Y	MT
SG+M	B	N	N	Y	MT
SG+M+PO	B	N	Y	Y	MT

P: Potential Field B: Composite Bézier Path Y: Yes N: No

PT: Pose-based Trajectory Tracking

MT: NMPC Trajectory Tracking with *Keyhole ZBF*

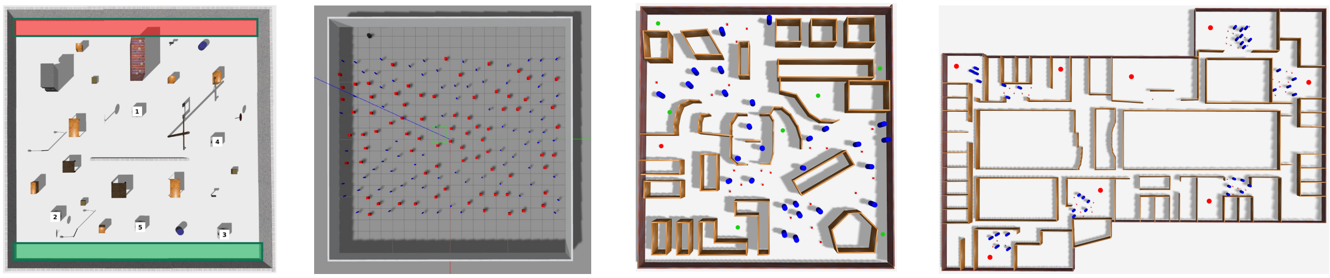
* PG+PO uses projection operator (PO) in every planning loop; SG+M+PO only needs PO if NMPC cannot converge within prescribed time.

† Generate time-varying trajectory with desired velocities.

$^-$ The feedback gains of path following are not tuned.

2 Benchmark Scenarios

Four simulation scenarios shown in Fig. 1. Start region/poses (red) and end region/poses (green) are labeled in sector and campus worlds. In the dense world, robots navigate from top to bottom. The start and goal poses are randomly chosen from the red points in the office world.



Sector Dense Campus Office

Figure 1: Four simulation scenarios. Start region/poses (red) and end region/poses (green) are labeled in sector and campus worlds. In the dense world, robots navigate from top to bottom. The start and goal poses are randomly chosen from the red points in the office world.

3 Results

The full ablation study results are in Table 1. We also compute average robot's linear velocity for each planner. We run 25 seeds for each scenario and repeat 5 times for each seed. There are 500 runs in total for each planner.

Table 2: Simulation results in STDR (1st order nonholonomic model) and Gazebo (2nd order nonholonomic model) scenarios

	STDR				**Gazebo**			
	Collision	Abort	Success	Avg ν (m/s)	Collision	Abort	Success	Avg ν (m/s)
PG$^-$	6%	1.2%	92.8%	0.45	12.6%	0%	87.4%	0.35
PG	2.2%	0.6%	97.2%	0.26	1.8%	0%	98.2%	0.26
PG+PO	0%	1%	99%	0.25	0.4%	0.4%	99.2%	0.25
SG$^-$	8.2%	18.2%	73.6%	0.44	26%	21%	53%	0.4
SG	0.4%	2.4%	97.2%	0.33	0.4%	2%	97.6%	0.34
PG+P	22.6%	4%	73.4%	0.4	18%	13.4%	68.6%	0.4
SG+P	16.8%	19.4%	63.8%	0.39	26.4%	16.4%	57%	0.38
PG+M	5.8%	16%	78.2%	0.29	3.4%	19.2%	77.4%	0.27
SG+M	4.4%	4.2%	91.4%	0.3	0.6%	5.6%	93.8%	0.28
SG+M+PO	0%	0.8%	99.2%	0.3	0%	0.4%	99.6%	0.28

We can find that SG+P has lower collision rate and higher abort rate than PG+P in STDR. Composite Bézier path planning has less collisions than potential gap given 360° sensing. However, the collision rate of SG+P increases and is higher than PG+P in Gazebo with 60° FoV. Considering average linear velocities, PG$^-$ and SG$^-$ have faster speeds than PG, PG+PO, and SG. After adding trajectory synthesis, the speeds are slower in PG+M, SG+M, and SG+M+PO to have less collision rates. But they are faster than PG and PG+PO.