Evaluation Metrics for Mobile Robot Local Planning Approaches

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In this letter, three types of evaluation metrics for mobile robot local planning approaches are detailed. To facilitate the subsequent introduction, we first introduce the data we need to log during the navigation process. Then the safety, efficiency, and smoothness metrics are presented respectively.

1 Data Log

Suppose that in the process of robot navigation from the start pose to the goal one, the local planning is called N times. Every time the local planning is called, we need to log the following data: the timestamp of the i-th call t_i, the robot pose (x_i, y_i, θ_i), the linear and angular velocities (v_i, ω_i), the distance to the closest obstacle d_i, and the time consumption of the local planning c_i. When the robot completes the navigation task, we obtain the intermediate data of the whole navigation process $\{t_i, x_i, y_i, \theta_i, v_i, \omega_i, d_i, c_i\}, 1 \leq i \leq N$.

2 Safety Metrics

The safety metrics are employed to evaluate the security performance of local planners in guiding the robot to the goal. In this letter, the minimum distance to the closest obstacle d_o and the percentage of time spent by the robot in the dangerous area around obstacles p_o are used to evaluate the security of local planners

$$d_o = \min\{d_i\}, 1 \leq i \leq N, \tag{1}$$

$$p_o = \frac{\sum (t_b - t_a)}{t_N - t_1} \times 100\%, \tag{2}$$

where the subscripts a and b are the indices of timestamps satisfying $d_k \leq d_{\text{safe}}, a \leq k \leq b$, and d_{safe} is the preset safety distance to obstacles. The distance to the closest obstacle d_i is obtained by combining an efficient distance transform algorithm described in [1] and bicubic interpolation on top of the occupancy grid map.

3 Efficiency Metrics

The efficiency metrics are used to evaluate the motion efficiency and computational efficiency of local planners. The motion efficiency measures how quickly the local planner guides the robot to the goal, and the computational efficiency evaluates the real-time performance of local planners. In this letter, the total travel time T of the robot from the start to the goal is used to evaluate the motion efficiency

$$T = t_N - t_1. \tag{3}$$

And the computational efficiency is measured as the average period between the time when the local planner receives the planning request and the time of the updated twist command becoming available

$$C = \frac{1}{N} \sum_{i=1}^{N} c_i. \tag{4}$$

4 Smoothness Metrics

The smoothness metrics are employed to evaluate the quality of motion commands provided by local planners. In this letter, the smoothness performance of local planners is comprehensively evaluated by the path smoothness and velocity smoothness. We broadly follow the smoothness constraint defined in [2] to evaluate the path smoothness

$$f_{ps} = \sum_{i=2}^{N-1} \left\| \boldsymbol{\Delta}\mathbf{x}_{i+1} - \boldsymbol{\Delta}\mathbf{x}_i \right\|^2, \tag{5}$$

where $\boldsymbol{\Delta}\mathbf{x}_i = \mathbf{x}_i - \mathbf{x}_{i-1}, 2 \leq i \leq N$ denotes the displacement vector at the vertex $\mathbf{x}_i = (x_i, y_i)^{\mathrm{T}}$. And the velocity smoothness is measured by the average of the acceleration

$$f_{vs} = \frac{1}{N-1} \sum_{i=1}^{N-1} \left| \frac{v_{i+1} - v_i}{t_{i+1} - t_i} \right|. \tag{6}$$

References

[1] P. F. Felzenszwalb and D. P. Huttenlocher, “Distance transforms of sampled functions,” *Theory of Computing*, vol. 8, no. 1, pp. 415–428, 2012.

[2] D. Dolgov, S. Thrun, M. Montemerlo, and J. Diebel, “Path planning for autonomous vehicles in unknown semi-structured environments,” *The International Journal of Robotics Research*, vol. 29, no. 5, pp. 485–501, 2010.