Learning Forward Dynamics Model and Informed Trajectory Sampler for Safe Quadruped Navigation

APPENDIX

A. Command sequence sampling to train FDM

To capture broad command sequence distribution, we generated command sequence data via linear time-correlated command sampling (Eqn. 1), normal time-correlated command sampling (Eqn. 2), and constant command sampling (Eqn. 3) in same proportion. For all sampling methods, $c_0 \sim U(c_{min}, c_{max})$.

$$
\begin{aligned}
\beta &\sim U(\beta_{min}, 1) \\
c_{rand} &\sim U(c_{min}, c_{max}) \\
c_{t+1} &= \beta \cdot c_t + (1-\beta) \cdot c_{rand} \\
&\forall\, t \in \{0...T-1\},
\end{aligned}
\tag{1}
$$

$$
\begin{aligned}
\sigma &\sim U(0, \sigma_{max}) \\
c_{t+1} &\sim N(c_t, \sigma) \\
&\forall\, t \in \{0...T-1\},
\end{aligned}
\tag{2}
$$

$$
\begin{aligned}
c_{rand} &\sim U(c_{min}, c_{max}) \\
c_t &= c_{rand} \\
&\forall\, t \in \{0...T-1\},
\end{aligned}
\tag{3}
$$

B. Hyperparameters

Number of environments	800
Learning rate	3e-4
Batch size	512
Data buffer size	45000 samples
Cross entropy loss weight	2.0
Mean squared error weight	1.7
Single data collection period	9 [s]
State encoder hidden units	[256, 256, 128, 128, 100]
Command encoder hidden units	[32, 64]
Recurrent layer hidden units	100
Number of recurrent layers	2
Coordinate predictor hidden units	[64, 32, 16, 2]
Collision predictor hidden units	[64, 32, 16, 1]
Activation function	LeakyReLU
Batch Normalization	True
Dropout	0.2

TABLE I: Hyperparameters used for training FDM. Last values in the list of hidden units are output units

β	0.4
γ	10
σ	[0.3, 0.12, 0.36]
H	12
N_b	9
Number of samples from random sampler	729 (=9^3)
Number of samples from ITS	100

TABLE II: Hyperparameters used for sampling-based model-predictive control module

Learning rate	3e-4
Batch size	256
State encoder hidden units	[256, 256, 128, 128, 100]
Waypoint encoder hidden units	[32, 64]
Command encoder hidden units	[32, 64]
Waypoint recurrent encoder hidden units	100
Command recurrent encoder hidden units	100
Latent vector dimension	16
Latent encoder hidden units	[64, 32, 16]
Latent decoder hidden units	[64, 64, 32]
Command recurrent decoder hidden units	32
Command decoder hidden units	[32, 3]
Activation function	LeakyReLU
Batch Normalization	True
Dropout	0.2

TABLE III: Hyperparameters used for training ITS. Last values in the list of hidden units are output units. Model weights of state encoder and command encoder were fixed with the weights in FDM.

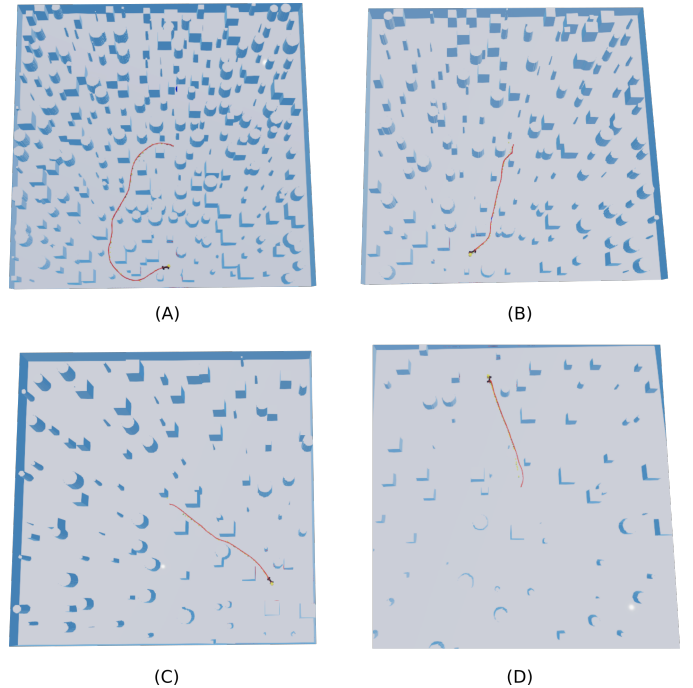### C. Point Goal Navigation in open fields

Fig. 1: Map and the robot's traversal path in open field environments. (A) to (D) each is environment with obstacle grid size 2.3, 3, 4, 5 m, respectively

Generated random environments with sampled endpoints did not always show a feasible path. Specifically, the global

planner, BIT* in our work, sometimes failed to find a coarse path connecting the sampled endpoints due to very densely located obstacles. In this case, we sampled a different endpoint or generated a different environment with the random environment generator.