A Deep Reinforcement Learning Framework and Methodology for Reducing the Sim-to-Real Gap in ASV Navigation

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Introduction

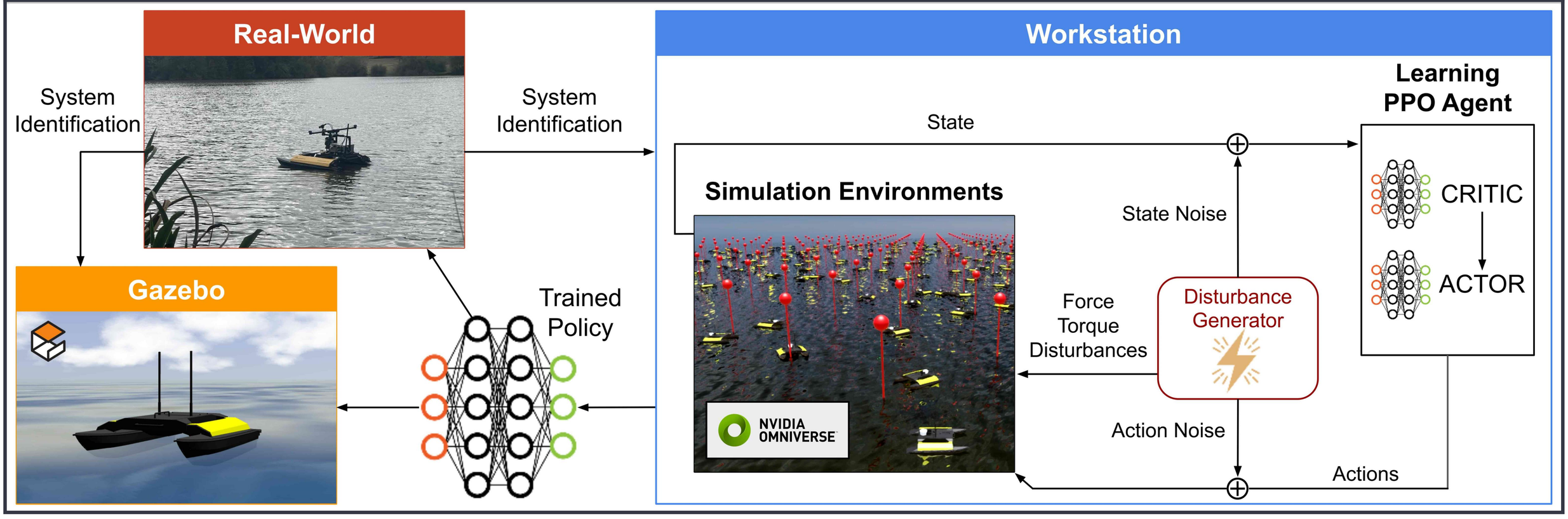
(a) Isaac Sim (b) Gazebo (c) Real ASV

- A framework integrating RL with system identification and domain randomization. It includes a RL training environment, validation simulator, and field tests to reduce the sim-to-real gap in ASV navigation and enhance efficiency.

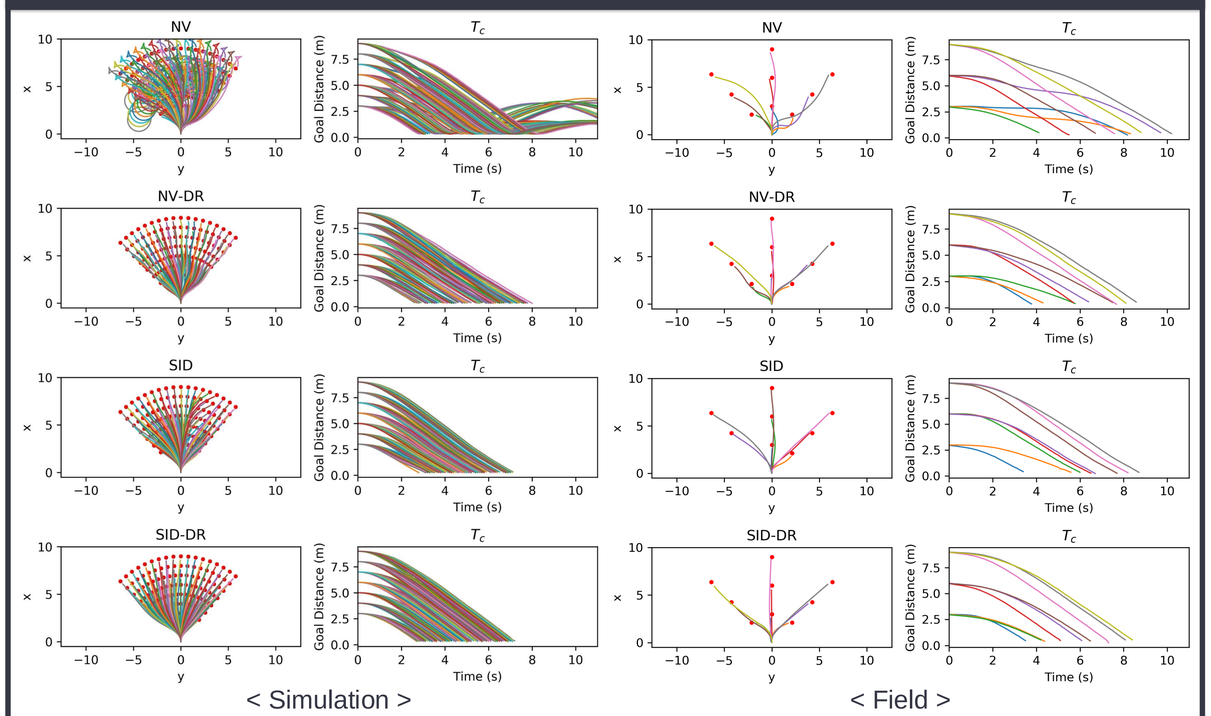
Key Contributions

- Open-source, highly parallelized hydrodynamics and buoyancy implementation suitable for reinforcement learning framework
- Methodology to reduce the sim-to-real gap by combining System Identification with Domain Randomization for Deep Reinforcement Learning.
- Real-world experimental evidence illustrating that our approach can minimize battery energy consumption and simultaneously speed up task completion.

Framework Overview



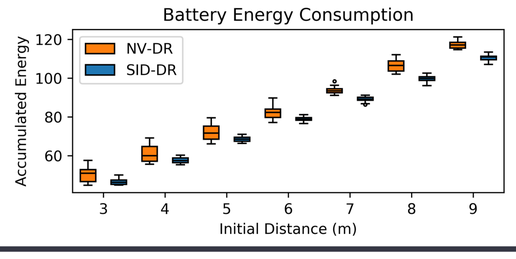
Result



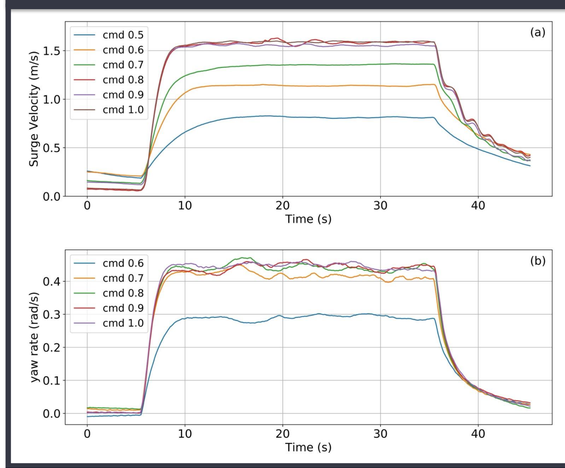
< Simulation >

		$T_c(s)$			E_{acc}		
	Goal distance	$3m$	$6m$	$9m$	$3m$	$6m$	$9m$
Sim	NV	4.0	15.4	16.9	63.2	236.6	269.8
	NV-DR	3.2	5.3	7.3	50.2	82.3	117.5
	SID	3.3	5.0	6.9	44.7	81.0	116.1
	SID-DR	3.0	4.9	6.7	46.6	78.9	110.5
Real	NV	6.9	7.3	8.9	105.8	114.9	139.1
	NV-DR	4.6	6.5	8.1	77.8	105.4	131.9
	SID	4.5	6.4	8.2	74.9	88.6	123.3
	SID-DR	4.0	5.9	7.9	57.8	90.8	125.2

< Field >



Methodology



Hydrodynamic coefficients:

$$\mathbf{D}_l = \begin{bmatrix} X_u & 0 & 0 \\ 0 & Y_v & 0 \\ 0 & 0 & N_r \end{bmatrix} \quad \mathbf{D}_q(\nu) = \begin{bmatrix} X_{u|u|}|u| & 0 & 0 \\ 0 & Y_{v|v|}|v| & 0 \\ 0 & 0 & N_{r|r|}|r| \end{bmatrix}$$

Observation:

$$\mathbf{o}_t = [u_t \quad v_t \quad r_t \quad \cos(\delta_t^{\text{head}}) \quad \sin(\delta_t^{\text{head}}) \quad d_t]^T$$

Action:

$$u_t = [u_t^{\text{left}} \quad u_t^{\text{right}}]^T$$

Reward:

$$r_t = r_t^{\text{dist}} + r_t^{\text{head}} + r_t^{\text{energy}} + r_t^{\text{alpha}} + r_t^{\text{time}} + r_t^{\text{goal}}$$

Conclusion

- Enhanced a highly parallelizable RL framework by integrating buoyancy & hydrodynamic models.
- The proposed framework could improve the task time and energy efficiency in real-world field tests for waste capture.

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