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Towards Robust and Adaptive Decision-Making in Autonomous Robots: A Framework for Synchronized Digital Twins

The use of autonomous mobile robots in dynamic and uncertain environments requires adaptive and robust decision-making. Synchronized digital twins —real-time virtual counterparts of physical systems — offer a promising approach to improving planning, increasing robustness, and enhancing adaptability. However, developing such systems presents significant challenges, including balancing real-time synchronization with computational efficiency, ensuring the robustness of sensor fusion under domain shifts, and integrating learned models into real-world applications. This work identifies and investigates these challenges and explores how to address them. Therefore, existing approaches in synchronized digital twins for autonomous mobile robots are compared, identifying their strengths and limitations. Based on these insights, a conceptual framework that integrates simulation-driven reinforcement learning with real-time adaptation mechanisms under safety constraints is proposed. The framework is designed for efficient deployment across diverse robotic platforms and tasks. By contributing to bridging the gap between simulation and real-world execution, this research aims to advance the deployment of autonomous robots in safety-critical and unstructured environments.

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