

System-Level Safety Monitoring and Recovery for Perception Failures in Autonomous Vehicles

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Abstract—The safety-critical nature of autonomous vehicle (AV) operation necessitates development of task-relevant algorithms that can reason about safety at the system level and not just at the component level. To reason about the impact of a perception failure on the entire system performance, such task-relevant algorithms must contend with various challenges: complexity of AV stacks, high uncertainty in the operating environments, and the need for real-time performance. To overcome these challenges, in this work, we introduce a Q-network called SPARQ (abbreviation for Safety evaluation for Perception And Recovery Q-network) that evaluates the safety of a plan generated by a planning algorithm, accounting for perception failures that the planning process may have overlooked. This Q-network can be queried during system runtime to assess whether a proposed plan is safe for execution or poses potential safety risks. If a violation is detected, the network can then recommend a corrective plan while accounting for the perceptual failure. We validate our algorithm using the NuPlan-Vegas dataset, demonstrating its ability to handle cases where a perception failure compromises a proposed plan while the corrective plan remains safe. We observe an overall accuracy and recall of 90% while sustaining a frequency of 42Hz on the unseen testing dataset. We compare our performance to a popular reachability-based baseline and analyze some interesting properties of our approach in improving the safety properties of an AV pipeline.

Website: kaustavk.github.io/sparq

I. INTRODUCTION

Safety of autonomous vehicles (AVs) heavily relies on the correctness of perception systems. This has spurred a plethora of work in developing monitors aimed at detecting perception failures [1]–[4]. However, triggering a fail-safe maneuver for every detected perception error is impractical and detrimental to the AV’s navigation goals. Not all perception failures are equal; some bear no impact on the AV’s safety (e.g., missed parked vehicle far off from the AV’s motion plan), while others can be catastrophic (e.g., missed pedestrian along the AV’s motion plan); the latter are referred to as task-relevant (or system-level) perception failures [5]. Identifying task-relevant perception failures and reacting to them poses significant challenges: First, the AV operates in highly uncertain environments, making it difficult to assess the system-level impact of perception failures. Second, these monitors must assess the system-level impact of complex AV stacks at run-time, ideally at a much higher



Fig. 1: We propose SPARQ, a run-time system-level safety monitor to detect and mitigate task-relevant perception failures. Here, the perception suite failed to detect the red car. This resulted in AV (the green car) planning an unsafe trajectory (blue line). SPARQ flags the planned trajectory as unsafe and suggests a corrective safe plan (cyan line) that accounts for the perception failure.

frequency than the AV stack. Finally, even if the perception failure is detected, there might not be enough time to replan a safe motion accounting for the perception errors. In this work, we address these challenges by developing a Q-network-based monitor called SPARQ (abbreviation for Safety evaluation for Perception And Recovery Q-network) that, in real-time, detects task-relevant perception failures and generates corrective recovery plans. We envision a task-relevant perception monitoring and recovery pipeline that has four main blocks: a component-level *perception monitor* that identifies the failure mode that is occurring, a *plausible scene generator* which produces plausible scenes accounting for the perception failure, a *safety monitor* which quantifies how risky it is to execute a given motion plan in the plausible scenes while accounting for the uncertain future predictions of other agents, and finally, a *recovery planner* which generates a recovery maneuver in the event of a task-relevant perception failure (see Fig. 2 for the block diagram). Unfortunately, perception monitors have very stringent compute requirements and need to run at frequencies much higher than that of the AV stack, which makes it infeasible to run such an intricate monitoring pipeline online – indeed, the slow speed of the modular monitoring pipeline was something we observed in our previous work [5] as well. SPARQ resolves this problem by learning a neural approximation of the last three blocks, providing run-time capabilities for our task-relevant perception monitoring and recovery pipeline.

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