Tradespace Exploration of Sensor Architectures for Autonomous Vehicle Navigation

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Increased levels of autonomy are crucial to the success of exploration missions in unknown environments. Specifically, a vehicle’s ability to locate itself and the landmarks in its surroundings, known as the Simultaneous Localization and Mapping (SLAM) task, impacts greatly its path planning capabilities, and therefore the quality of the information collected during an exploration course.

The main performance indicator of a sensing suite for SLAM, that does not require ground truth information, lies in the certainty with which positions are estimated. In addition to this precision metric, other figures of merit emerge to evaluate sensing systems for SLAM. In energy constrained environments, low-consumption sensor suites are desirable. Similarly to the energy constraint, computing power can be limited on smaller vehicles, and the complexity generated by the data produced by the sensor suite should entail enough information for the estimation problem to be solved, while being kept at a minimum to reduce processing overloads and system latency. Finally, if the sensing system is meant to be reproduced on many different vehicles of a fleet, cost-mindful systems should be preferred for similar levels of precision, energy, and computation complexity. These objectives are usually competing with one another; for example a LiDAR, which provides precise measurements of landmarks but also a high number of feature points to be analyzed, while consuming more energy and being more expensive than vision sensors.

Nevertheless, finding sensing architectures on, or near, the Pareto Front for these competing objectives cannot involve the factorial enumeration and evaluation of every possible combination of sensor, listed in a library containing half a dozen sensor types such as LiDARs, radars, and cameras, as we also wish to find the best position for each chosen sensor on the vehicle. Adding this choice to the selection problem enlarges the design space to a point where new methods have to be developed for architecture enumeration.

The selection problem is therefore formulated as an optimization problem, where precision is maximized, under energy, complexity, and cost constraints. These constraints are then progressively relaxed to map the design tradespace. The objective function exhibits a diminishing returns property, also called submodularity, as estimation precision increases more and more marginally as sensors are added on the vehicle. A greedy algorithm, known in single objective optimization of submodular function, is leveraged and transformed to find near-optimal architectures in the several dimensions of interest. The presentation will detail this method, as well as present near-optimal sensor placements for autonomous vehicles as a function of their route and the environment they explore.