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Probabilistic Algorithms for Odor Source Localization using a Distributed System

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Odor source localization (OSL) consists of finding the location of a source of chemical release by gathering sample measurements in the environment and moving toward points of interest. This is a difficult task due to the complicated dispersion of the plume of gas. It appears in various situations, the main applications being search and rescue, security operations and industrial inspection. Different ways of solving this problem have been developed, either with static or mobile sensors. OSL using a probabilistic source term estimation (STE) algorithm has already been implemented, tested and validated in simulated environments as well as real setups involving a single robot [1]. This project aimed to extend the framework to multi-robot cooperation, as illustrated in Figure 1.

Figure 1: Setup for OSL involving a team of robots.

For this purpose, different strategies were designed to improve the efficiency of the algorithm in the context of a distributed system. A radio transmission was used for communicating data between teammates. Simple information that can be transferred between robots includes the robot's location, the gas concentration it measured at that location, as well as the resulting entropy and expected or maximum a posteriori value of its posterior probability distribution. Possible strategies were therefore designed on the basis of those elements. All the implemented strategies are low-cost in terms of computation time, communication load and memory needs. This is essential because the STE algorithm is already heavy. Since the general algorithm consists of three main phases, namely estimation, navigation, and declaration, the various strategies implemented in this work were conceived such that they take place in one of these three categories. Furthermore, different estimation and navigation strategies can be combined for efficient information seeking, as well as for balancing exploration of the environment and exploitation of information.

Estimation strategies were intended to tune both the quantity and quality of information transmitted to teammates in view of minimizing the communication load and processing time. Navigation strategies were constructed with properties of probability density functions, allowing to coordinate the motion of robots with respect to the confidence level associated with their belief. Declaration strategies were dedicated to reducing the overall duration of the localization task by considering a team of robots that trust each other or try to establish a consensus on their estimation, while ensuring a high confidence level on the estimate of the source location.

Estimation strategies included full communication, stochastic communication, and emitter entropy reduction. Navigation strategies were individualist, PSO-inspired, and certainty-weighted MAP. Declaration strategies consisted of independent declaration, first low entropy, many low entropy, and consensus on MAP. Each of those strategies was associated with convenient parameters. In simulation, the performance of a variety of strategy and parameter combinations was assessed. In particular, it was found that none of the cooperative navigation strategies outperformed the individualist navigation under full communication. Estimation with full communication led to the best performance with every navigation strategy. Navigation methods combined with other estimation strategies were not able to increase the performance on the number of algorithm cycles achieved with full communication. However, the main enhancement occurs on the communication load, since the ratio of personal observations is higher with stochastic or entropy reduction strategies. The consequence is that robots need a little more time to make their estimates converge, but the difference is negligible compared to the reduced cost of communication power and data processing. In the end, the most efficient strategy was emitter entropy reduction for estimation combined with PSO-inspired navigation using a team of five robots.

[1] F. Rahbar, A. Marjovi, and A. Martinoli, "An algorithm for 3D Odor Source Localization through Source Term Estimation," submitted to *IEEE International Conference on Robotics and Automation*, May 2019.