Autonomous Trajectory Planning for Mapping Deep Sea Hydrothermal Plumes

Genevieve Flaspohler

Advisor: John W. Fisher III

MIT CSAIL

geflaspo@mit.edu

Abstract:

We develop and deploy an autonomous experimental design framework for plume localization and characterization. The mathematical formulation and associated algorithms generalize to a broad range of localization problems. For demonstration purposes, we present results on a real-world application – mapping deep sea hydro-thermal plumes. Deep sea hydrothermal plumes act as heat, nutrient, and chemical pumps in the deep ocean, supporting unique ecosystems. However, localization and direct observation are challenging due to their variable spatiotemporal nature. Plumes are influenced by tidal advection and turbulent mixing on both short (sub-hour) and long (seasonal) timescales. Plume structures span multiple spatial scales, from kilometers in the non-buoyant layer to tens of meters in the buoyant stem. Key plume drivers such as entrainment, currents, and buoyancy flux are inherently challenging to measure. These elements have analogs in similar autonomous monitoring and mapping problems applications.

The approach combines complementary sensing modalities – autonomous underwater vehicles (AUVs), remotely operated vehicles (ROVs), CTD casts, and bottle samples – to map deep sea hydrothermal plumes. CTD casts resolve vertical plume structure at large scales; dense and repeated horizontal AUV surveys enable spatiotemporal mapping; targeted ROV deployments can characterize plume source parameters; and finally, bottle samples provide deeper understanding of biogeochemical cycling in plume waters. The resulting algorithm for generating deployment plans consists of three components: 1) a trajectory optimization method, which chains canonical "lawnmower" AUV surveys to track a probabilistic plume forecast, 2) a high-level task planner that quantifies uncertainty in the plume model and targets CTD and ROV surveys to reduce this uncertainty, and 3) an opportunistic sampling algorithm that collects scientifically useful bottle samples. Results from a November 2021 Guaymas Basin research cruise utilizing the AUV Sentry and ROV Jason demonstrate that autonomous decision-making can advance the efficiency and robustness of operational mapping and localization.