

2.10 Multiscale Actuated Sensing (MAS)

Multiscale actuated sensing research activities have focused on the core algorithmic challenges of incorporating rich image media and mobility as key components of environmental sensing systems, in particular: planning, design and calibration, and vision-based sensing, spatial sampling, and tracking.



Figure 8. Deployed Glider resting at the surface.

Planning, Design and Calibration

Trajectory design for Autonomous Underwater Vehicles (AUVs; Figure 8) is of great importance to the oceanographic research community. We consider the use of ocean model predictions to determine the locations to be visited by mobile sensor platforms. The platforms, in turn, provide near-real time, in situ measurements back to the model to increase the skill of future predictions. We have expanded upon our previous proof-of-concept results and demonstrated open-ocean implementation with multiple vehicles on data-gathering campaigns in the Southern California Bight (SCB). We have also investigated the impact of the use of predicted ocean currents on the trajectory design process for underwater vehicles. We take an Informative Path Planning approach to the robot path-planning problem. We aim to choose measurements that best describe a scalar field of interest (e.g. temperature). Given a model for the underlying scalar field we are able to compute the covariance and entropy

of the field given a hypothetical set of sample locations. Using this model of the underlying field, we maximize the mutual information of the un-sensed locations with respect to the sensed locations, resulting in good AUV paths. A coastal communication system provides a fast, safe, affordable way of communicating with the underwater vehicles through a RF-modem base-station network installed in the Southern California region. Using this method we measure a 6x improvement (24x with compression) in file transfer speed, compared to Iridium. We determined experimentally that the feasible communication range using this method is approximately 12 km. Experiments with a month-long deployment in the SCB provide evidence that sea state is a factor that affects range due to the low antenna position. In collaboration with MBARI, we have used data available from a range of sources, including ocean models, remote sensing satellites, moorings, and on-shore instruments to predict the trajectory of a patch of water. In experiments targeting the Monterey Bay (a biologically diverse bodies of water that experiences extreme "red-tide" blooms), an ideal location for algal bloom studies. An advection analysis of bloom "hotspots" from October 2007 and October 2008 data in the Monterey Bay shows an example of how such predictions can be used to plan survey missions for AUVs. Finally, our recent work has demonstrated that visual and inertial sensors, in combination, can provide very accurate estimates of the ego-motion of a robotic sensing platform. The accuracy of the motion estimate depends, however, on proper calibration of the transform between the camera and the inertial measurement unit (IMU). Un-modeled calibration errors will introduce biases in the estimation process, degrading overall localization performance —sometimes dramatically. Although accurate calibration is critical, many existing camera-IMU calibration techniques are difficult, time-consuming and require additional complex apparatus. We have developed algorithms to circumvent many of these problems. Using these techniques we are able to accurately predict drift in the (purely inertial) estimates of AUV position.

Vision-based Sensing, Spatial Sampling, and Tracking

There exist many biological sensing applications where direct measurement is impossible, invasive, or time consuming. For example, measuring the presence/absence of birds at a feeder station currently requires a human to watch a camera pointed at the feeder, identifying when birds arrive and leave. Similarly, measuring CO₂ flux from a plant requires placing the plant inside a growth chamber, destructively modifying the environment. We use imagers as biological sensors by constructing a procedure that uses images to obtain approximate measurements of such phenomena. This procedure, composed of state-of-the-art computer vision, image processing, and statistical learning algorithms, is evaluated in the context of two specific applications: automatically detecting and segmenting out animals from a natural scene, and pollinator counting. Our approach to bird localization is to first localize by exploiting the fixed view deployment scenario, and cluster detections based on the similarity of appearance and spatiotemporal coherence. We introduce a discrepancy measure that has several useful properties for multi-view categorization in the context of surveillance and monitoring applications. For pollinator counting, the procedure roughly consists of three independent pieces. For each frame, we first localize the region of interest as specified by the user. This effectively discards a large fraction of each frame that is uninteresting, by definition, and would only serve to confuse further processing. Next, we detect and localize the target as it occludes the region of interest. Finally, using the

match value and location of a potential match produced by the target detection, we track the target's motion over time, leveraging the inherent temporal correlation between frames to discard false detections. We also propose a method for classifying the vegetation types in an aerial color infrared image. Different vegetation types do not only differ in color, but also in texture. We study the use of four Haralick features (energy, contrast, entropy, and homogeneity) for texture analysis, and then perform the classification using the One-Against-All (OAA) multiclass Support Vector Machine (SVM). Whether using imagers or other modalities, detecting, localizing, and tracking targets are different aspects of monitoring that have wide applications. We propose the use of a new random set theory (RST) approach to these problems. RST is a theory developed on random sets, which generalizes probability theory to the set domain. We use this theory to model sensor failures, lost connections, noise, and clutter. In sensor networks, for dynamic events, classical joint estimation/detection/tracking multi-sensor and multi-target algorithms are often hybrids of both analytical and ad-hoc approaches at various levels. The intricacies of the resulting solutions when the number of targets and sensors may vary randomly often obscure design intuition and leave many design choices to a largely trial and error based approach. By treating multi-target and multi-sensor cases jointly, RST is able to provide a systematic framework for rigorous mathematical analysis. A rigorous statistical framework has been developed for RST that includes concepts as: ML, Bayesian filtering, data fusion, and Cramer-Rao Bound.