2.9 Multiscale Actuated Sensing (MAS)

Planning, Design and Calibration

Trajectory design for Autonomous Underwater Vehicles (AUVs) 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. A simple planning strategy and algorithm have been developed which determine relevant points of interest for a chosen oceanographic feature. This strategy represents a first approach of an end-to-end autonomous prediction and tasking system for aquatic, mobile sensor networks. Most AUVs are not able to hover in an energy-efficient manner at a benthic feature of interest. We have developed a novel benthic robotic observing system designed to periodically patrol a transect, while capturing images of the water above it. Using a combination of inertial sensing, absolute position measurements at the transect endpoints, and a simple dynamic model, we are able to apply a Kalman smoother to obtain accurate position estimates for the robot. These estimates are used a posteriori to align sensor scans of the water made by the main observational instrument on the robot—an Acoustic Doppler Current Profiler (ADCP). The aligned scans produce a map of unprecedented accuracy and coverage A pilot deployment done at commercial marina demonstrates accurate observation of water flow rate and water flow direction across a section of the marina inlet. 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. 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.

Control and Communication in Robot Teams

Communication plays an important role in the design of collaborative systems. We have focused on three specific challenges in this context. The first, driven by immediate mission needs for aquatic sampling is based on the observation that our AUVs (gliders), when on a mission, use a satellite phone to communicate with the shore—this is expensive. In an effort to reduce these costs, we have designed, developed, deployed and tested several stages of a communications framework, which uses radio frequency communication with shore-based stations. The second area of investigation focuses on the idea that in certain situations, it may be advantageous for AUV teams to communicate without surfacing (e.g., using acoustic communication). Acoustic channels suffer from significant attenuation, dependent both on frequency and distance. There is extensive time-varying multi-path, motion-induced Doppler distortion as well as an introduction of delays due to the low speed of sound—something not easily noticeable in radio or optical communication mediums. This severely limits the available bandwidth as well as varies the communications performance with distance. We have studied the effect of acoustic communication on a simple control task (station keeping on a robot boat) and find that while individual nuisance factors do not destabilize the controller, when present concurrently, even small amounts of noise can have a detrimental effect on the control system. The third area of emphasis models reliable communication as redundant connectivity. Specifically, we study the following planar problem in a laboratory setting. Given a network of robots, plan and execute a minimal sequence of robot movements that will cause the network to become biconnected. We propose an algorithm that uses relative bearing to plan a minimal sequence of robot movements. Under the disk model, the number of edges in the network graph is guaranteed to increase monotonically. Simulations reveal that the algorithm is robust to bearing error, which means that in practice it is usable with a network of robots that use only commodity radios to compute relative bearing. This is validated with experiments using a network of physical robots.

Vision-based Sensing, Spatial Sampling, and Tracking

There exist many 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. 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 a specific application and has been shown to be general through multiple instantiations. Over the last few years, computer vision has made many advances towards generalized detection, localization, recognition and categorization. We focus on applying these techniques to specific applications. One of our goals is to make it possible for anyone to capture interesting moments from nature. We are building a system that allows a person to define what they are interested in seeing, rather than a general model of what is "interesting". Any person with a web browser and a webcam should be able to capture video continuously throughout the day. Our system should return proposed clips, effectively filtering irrelevant data and allowing users to focus on their interests. In a related project we also combining vision and machine learning techniques to monitor the traffic flow and crowd population on street images captured using cellphones. In a continuing effort, we study sampling problems for model selection in the context of spatial sampling of an environmental field (e.g. temperature, light, humidity) in order to select the best regression model, which describes the process, from a set of plausible models. We developed an adaptive sampling algorithm to sample the field with a set of static sensors and one mobile sensor. The algorithm aims to jointly minimize the probability of error in the selection, and the mobility cost. 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 finite set theory (RFST) approach to these problems. RFST is a theory developed on random sets, which generalizes probability theory to set domain. We use this theory to model sensor failures, lost connections, noise, and clutters.