MAS 05 Informative Path Planning

MAS 05.1 Overview
My goal is to create path planning algorithms that give mobile robots a high degree of autonomy. Many projects within CENS involve environmental monitoring. Static sensors can provide high temporal resolution measurements, but lack spatial resolution unless a very large number are used. Because of this, it is advantageous to use robots that can traverse the environment and provide samples on demand. In order to best take advantage of the mobile sensing capability that robots provide, it is necessary to come up with a path planning algorithm that can choose paths which gather the most useful information.

Over the past year, I have focused primarily on path planning for underwater gliders, which our lab has two of. The gliders have sensors which can measure the temperature and salinity of the water, among other things. They move slowly through the water, but are capable of remaining at sea for weeks at a time. My work has focused on creating and testing informative path planning.

MAS 05.2 Approach
We take an Informative Path Planning approach to the robot path planning problem. In this approach, we aim to choose measurements best describe a scalar field of interest (e.g. temperature or salinity). We assume that we have some model for the underlying scalar field which allows us to compute the covariance and entropy of the field given a hypothetical set of sample locations. Using this model of the underlying field, our goal is to maximize the mutual information of the unsensed locations with respect to the sensed locations.

We specify the path planning problem as one of finding a path on a discrete graph. Each point in the graph represents a possible waypoint for the glider, and each edge represents a possible path leg between two waypoints. The weight of each edge represents the cost (in time or power) of traversing it. Our goal is to find a path from a node s to a node t, the total cost of which is less than some budget B, which maximizes the mutual information between sensed and unsensed locations.

Because the number of possible paths is exponential in the maximum path length, exhaustive search is not practical even for relatively small graphs. Fortunately, mutual information is submodular, which allows a more efficient approximate algorithm. Submodularity is basically the property of diminishing returns: once many measurements have already been taken, taking more measurements provides less new information.

Because of the submodularity of mutual information, we are able to use a modified version of Chekuri and Pal's recursive-greedy approximation algorithm. This algorithm provides a logarithmic approximation to the submodular orienteering problem in sub-exponential time.

MAS 05.3 Experiments
We tested our path planning algorithms using both simulated data and data collected in the field.

Experiments Using Real Data
To test our algorithm, we used salinity data collected by underwater gliders. We used a Gaussian process to model the data, and restricted the space of possible paths to two dimensions. Fig. 2 shows one resulting path, and the pilot data used.
Experiments Using Simulated Data
Because we do not have ground truth values for each location, there is a limit to the kinds of testing that can be done on real data. To do more thorough testing, we use data from the Regional Ocean Modeling System (ROMS) which is maintained by JPL. This system incorporates large amounts of sensor data to create estimates of temperature, salinity, and currents for the ocean off of the Southern California coast.

MAS 05.4 Accomplishments
During the reporting period, we have done several field tests to collect data for testing our algorithm. We have also done tests in simulation, and we have extended the algorithm itself to handle new and useful cases. The initial results of this work is given in our ICRA 2010 paper.

MAS 05.5 Future Directions
Over the next year, we would like to expand the usefulness of our algorithm by incorporating ocean current estimates to get more accurate travel times for the glider. We also plan on extending our algorithm to work on other kinds of mobile robots.