Overview
We have been involved in collaborative research that uses Slocum gliders to study Harmful Algal Blooms in the Southern California Bight region. The Southern California Bight (SCB) region is home to the ports of Los Angeles and Long Beach which collectively handle approximately 40% of all US container traffic. This large shipping traffic along with a significant presence of smaller crafts in the ocean necessitates careful path-planning to avoid risking collisions with ships while the vehicle is at the surface. All container ships as well as commercial passenger craft are mandated to transmit their locations to VTS terminals nearby to indicate their location, speed and so on using the Automatic Information System (AIS). We have analyzed AIS information from 2009 and 2010 for the SCB (see Figure 1), and use this processed data along with well-established path-planning algorithms to plan missions for the gliders which reduce risk while going between way-points chosen for the scientific mission.

Approach
We construct an occupancy grid map (Figure 4) with a grid size of 500m x 500m. This is the highest resolution that accommodates the largest ships currently operational, while also being comparable to the navigational accuracy of a glider. By this we mean that the, co-existence of a glider (at the surface) and a ship in the same cell on this map is highly undesirable even though it might not necessarily result in a collision. Our goal is to be able to plan paths that reduce the possibility of the occurrences of gliders surfing in risky regions on the map as far as possible. At the same time we also want to plan paths for the gliders that are useful to scientists running their scientific experiments in the given region. The path-planning algorithm we want to devise should be able to take as inputs a start and end location, as well as a budget on the amount of time the vehicle has to traverse this path, and it should be able to plan feasible paths that try to go between the given locations while sticking to the risk and budget constraints. To construct
the occupancy grid map we apply the following equation where \( O(x,y,t) \) is 1 when a given cell was occupied by a ship in the given time segment \( t \). We use \( \gamma \) to weight new observations higher than past observations, where \( 0 < \gamma < 1 \) and \( \| \).

\[
R(x,y) = \sum_{t'} \gamma' O(x,y,t') / \sum_{t'} \gamma' \tag{1}
\]

**System Description**

We employ two types of path-planning approaches to find paths that satisfy the budgetary, bathymetric and risk conditions. The first is to find the shortest path on the occupancy grid that satisfies the constraints imposed. To write this more formally, the problem we are solving deals with finding a path \( P \) consisting of waypoints \( (w_1, w_2, w_3, ..., w_N) \) where \( w_1 \) and \( w_N \) are given as the start and end waypoints, along with the maximum time \( T_{\text{max}} \) and a maximum allowable risk \( R_{\text{max}} \). The algorithm returns a feasible path \( P \) that satisfies the given constraints.

\[
\text{Time}(P) < T_{\text{max}} \tag{2}
\]

and

\[
\text{Risk}(P) < R_{\text{max}} \tag{3}
\]

where Time and Risk are the expected Time taken by the glider to travel along the path \( P \) while the Risk is a function that determines the maximum risk for each waypoint along the path.

We employ two methods to find feasible paths. The first involves doing a search for the shortest path between the start and goal waypoints that satisfies equations (2) and (3) using A* search using the heuristic of euclidean distance between waypoints. The second method involves randomly sampling waypoints and considering paths that satisfy the constraints listed above. Here we use two approaches, Probabistic Random Maps (PRMs) and Rapidly-exploring Randomized Trees (RRTs). These methods do not produce guarantee producing shortest paths, but they allow us to quickly sample the space for feasible paths. The PRM method allows us to generate a mesh-like set of highways connecting waypoints in regions with low-risk and then testing these for constraint-satisfaction.

**Accomplishments**

By employing the planning system we are currently working on, we can find paths that are feasible both in terms of allowable time for the mission as well as in keeping the collision risk below a specified threshold. Figure 3. shows the intermediate output of the PRM planner. The planner randomly samples the space for possible locations that do not violate the risk constraints, and then proceeds to find feasible paths that join these. It then selects the nearest node to
the start and end locations that allow safe traversal between the start and end locations. It will keep resampling the space to find a better path that meets the specified constraints. The paths found by the A* algorithm are the shortest paths between the waypoints which satisfies the risk and time-constraints. A* being an exhaustive search takes longer than the sampling-based methods, but seems to find a solution quickly enough to be practically applicable. We also perform A* on a combined cost-function of risk and distance, and try to minimize both subject to the constraint of total allowable time for paths.

Future Directions
A further extension of this problem relates to sequential decision making wherein the path is modified based upon information about ships at the surface. To do this, we plan to use models for ship-movement learnt from prior data to predict likely locations for the same ships into the future and to incorporate these to modify a previous plan for the glider to further reduce the expected risk it might face in the future. Here, the risk-map is probabilistic, dynamic and time-dependent which makes for a more interesting problem.

Publications
The work conducted over the past year, has not been published so far, but will be submitted to the Intelligent Robots and Systems (IROS) conference, 2011.