Through my research, it is clear that navigation techniques for autonomous underwater vehicles (AUVs) are still in a highly research-based, theoretic stage. There are many different techniques to consider for navigation. Some are more effective in certain scenarios, such as deep water, while others can be used in multiple environments. Some of these techniques are improved by working in collaboration with other techniques. And some can only be used on vehicles of a certain size or with a certain capability.

The paper titled *Autonomous Underwater Vehicle Navigation* seemed to give the best overview of this field. Although this paper is 10 years old, it does not appear to be outdated. More recent papers tend to corroborate the findings of this paper. The paper gives an overview of the different techniques available for AUV navigation. I will summarize each of the described techniques and emphasize any techniques that seem better suited for this project or techniques that would clearly not work for this project. This literature survey will then need to be expanded with more specific research into the techniques with the most promise for this task.

The first technique, called dead reckoning, is the most researched and supported of the ones available. Also, it happens to require the cheapest equipment and therefore has potential for poor position estimates. Generally a compass, a water speed sensor, a depth sensor, and maybe a pressure sensor are integrated to attempt to track velocity over time. The goal is to estimate location based on vehicle velocity over a given time period. Obviously there is great potential for error in high current environments, leaving room for improvement.

The inertial navigation system (INS) uses gyros and accelerometers to calculate acceleration and motion to on all three axes. This allows for more accurate tracking of vehicle location than dead reckoning. The drawbacks to an INS for a small AUV like the Stingray are power consumption and cost. These will need to be considered when choosing which combination of techniques to use. Another problem, which both dead reckoning and INS share, is that error increases infinitely with the distance traveled. The initial phases of this work will be such short distances (1 km) that this problem may not yet be evident. However, it needs to be considered as the project expands.

The next technique is referred to as either the Doppler Velocity Sonar (DVS) or the Doppler Velocity Log (DVL). Both of these are the same things, which is essentially a sonar sensor that pings down towards the sea floor and uses the reflections
over time to calculate velocity relative to the seabed. This technique is very useful in shallow water situations and therefore is an attractive option for this project. The paper *Advances in Doppler-Based Navigation of Underwater Robotic Vehicles* gives further insight into the benefits of the DVL technique. It describes specific algorithms and results for using low-cost bottom-lock doppler sonars. This and other papers will be essential if the DVL technique is pursued for this project.

Another technique that has shown promise is acoustic based navigation through either long baseline (LBL) or ultra-short baseline (USBL). Both of these involve arrays of external acoustic transducers placed, generally on buoys, in the area that the vehicle will be navigating. The concept is that the vehicle can triangulate its position based on the timing of acoustic signals from the transducers, which have known positions. LBL and USBL are different ways of accomplishing this technique. Both of these have two major drawbacks, especially for this project. First is the cost of deploying and configuring the array of transducers. Second, and probably more relevant to this project, is the problems with acoustics in shallow water due to reflection off of the sea floor. However, there is a lot of research being done in this realm, so more research is necessary to see if this can be utilized for this project.

The next technique is broadly known as geophysical navigation. This involves the use of an accurate *a priori* map of the environment combined with measurements of geophysical parameters, such as bathymetry, magnetic field, or gravitational anomalies. The main problems are cost of creating the *a priori* map and the computational complexity of finding a peak in the sensor data. The complexity can be reduced by limiting the types of sensor involved in the mapping, using lower resolution maps by only using this technique for disparate, important areas, restricting the vehicle orientation during sensor pulling, and finally by combining with other techniques to limit valid search area. Despite some of the drawbacks, this is still worth further investigation since the coverage area of this project is relatively small.

Another important technique is vision based navigation, which uses computer vision and classification to localize position and navigate accordingly. Vision based navigation can be used similarly to geophysical navigation if there is an *a priori* map with unique visual features. Also, computer vision could be used to navigate by following a path shown by a cable on the seabed. This solution as an example is described in the paper *Vision Based Autonomous Underwater Vehicle Navigation: Underwater Cable Tracking*. The paper describes the algorithms used to locate the cable in the image plane based on vision, acoustics, and Laplacian of Gaussian (LoG) filtering.

The paper *Positioning an Underwater Vehicle through Image Mosaicking* describes how apparent motion of images form a mosaic in by feature selection and matching, detection of dominant motion points, and homography computation. This type of
computer vision could be highly useful in this project since the environment involves relatively shallow, clear waters.

A final note with regard to techniques and resources is that there are underwater vehicle projects at my research lab, SPAWAR Systems Center Pacific. I do have some history with these projects, but I will gather more up to date information on the work being done, and potentially use that as a resource for navigation techniques.

I am preparing this project as if I am going to follow it to the final solution. Therefore, I am considering all the potential navigation techniques. This list can be reduced as the project moves forward and important variables such as funding and environment parameters become apparent. That said, the scope of the work actually done for this class will be contained to the work that can be done with the sensors already available on the Stingray vehicle. The exception to this will be sensors that can be acquired and installed within the time period of this class. This means that my main focus of my work will be vision based navigation. Also, there is potential for work involving dead reckoning or INS integration at a remedial level.

The long-term goals of this project will be different of other projects because of the attempt at an actual application of the theories of navigation. Also, the environment is very specific, so the implementation will be specialized and therefore different. Also, the vehicle chosen for this project, the Stingray is a new and creative platform that may allow for some new ideas along the way based on it control in the water. One such interesting topic could be an algorithm to maintain a position in a current using depth, pressure, velocity sensors, and the vehicles multiple control options.

This project is obviously meant for a longer timeline than this course, so the important part from my literature survey will be discovering a finite goal for the project by the end of the quarter. I will need to do more research and learn more about the state of the Stingray vehicle before this can be achieved.