**A System for Autonomous Tracking and Following of Sharks with an Autonomous Underwater Vehicle**

# Validation Framework


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# Chapter 5

# Experiments Description and Results

To validate the results manually, two types of experiments were required to be done in order to test the system. A stationary tag and moving tag (attached to a Kayak and another AUV). The first experiment approves the functionality of the AUV in localization of the shark and the second would approve it for moving goal tracking.

## 5.1. Stationary Tag Tracking

CCMS (Cal Poly Center for Coastal Marine Science, Avila Beach, CA) experiments were done for the first phase of validation. While the simulations gave some promising results, they required tests of the system as a whole in the real environment. For this part of testing, an acoustic tag was attached to a rope with an anchor a 100 meters away from the pier and 2 meters below the water's surface. During the experiment, the AUV's start position relative to the tag was varied to ensure that the tracking could be performed from every direction. Also, variation in distance from the tag was considered during the experiment for the AUV. In all of those experiments, the goal was to find the exact location of the tag.

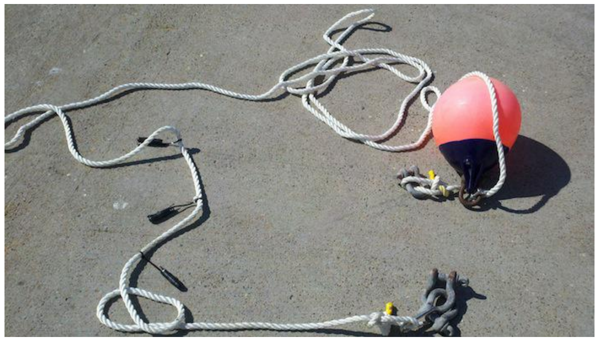

**Figure 5.1: Acoustic Transmitter Attached to a Buoy.**

**Figure 5.2: Cal Poly Pier, Avila Beach, CA.**

# 5.2. Moving Tag Tracking

After stationary tag tracking, the second approach was to track a moving tag which was attached to a Kayak and the goal was to follow the tag wherever it went. A three meter long rope was tied to the stern of a kayak and the depth of the acoustic tag was fixed at 2 meters below the water's surface. In those experiments, the kayak traveled in a wide variation of distance and bearing, both toward and away from the AUV. This helped to prepare for potential problems which may occur during a shark tracking operation.

# 5.3. Secondary AUV Tracking

Passing the first and the second phase ensured the functionality of the AUV manually. However visual functionality of the AUV was not adequate, therefore it was required to calculate the error rate in order to determine the accuracy of the AUV calculations. Therefore the acoustic transmitter was attached to the secondary AUV (AUV2). Both of the AUVs had GPS running and the control system on the AUV1 was logging the shark state estimation and AUV state information and the secondary AUV was logging the GPS data for itself. The main goal of those experiments was to track AUV2 by AUV1, compare the results and calculate the error rate.

**Figure 5.3: Transmitter Attached to The Second AUV.**

# 5.4. SeaPlane Lagoon Field Experiments

SeaPlane Lagoon is located close to Long Beach, CA. This was the final location for testing and tracking shark for the current research. Before tracking a shark, stationary and moving tests were performed to ensure the system’s functionality. By passing all of the tests, the final goal was to track a shark. Therefore a leopard shark (Triakis semifasciata) was caught, externally fitted with an acoustic transmitter tag, and tracked. In that area, because of shallow water, the rig on the AUV was shortened by the researchers to give the AUV enough room to operate.

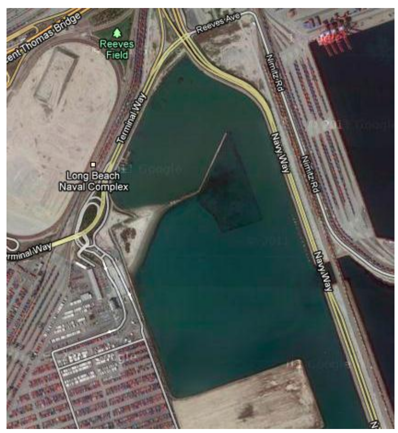


**Figure 5.4: SeaPlane Lagoon, Los Angeles, CA.**

# 5.5. Shark Tracking By AUV

The last results ensured the accuracy and ability of the system in performing tracking operations. In Long Beach experiments, the shark was pulled to the surface using the line, and was then gently restrained with a rope tied to its tail. Sharks have a biological response of tonic immobility, becoming still as though they are hypnotized, when they are turned upside down. This was used to keep the shark from moving while it was fitted with the tag. The entire procedure took less than 10 minutes. Once the tagged shark was released, the AUV was deployed to track and follow the shark.

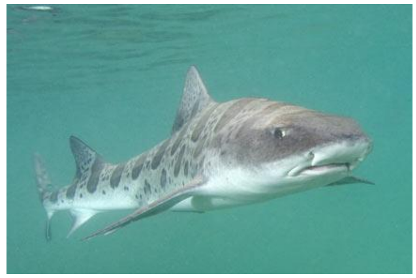

**Figure 5.5: Leopard Shark.**

# 5.6. Results

The AUV control system was designed to follow a shark autonomously with a small error value. To track a shark two states must be given to the control system: 1) Current state of AUV (includes location and bearing), and 2) Estimated location of the shark. Ability in tracking a shark can be evaluated when the AUV can easily track the shark in a proper direction. As discussed in the previous sections, to evaluate the control system several types of tests were done in order to ensure about the functionality of the system.

## 5.6.1. Stationary Tag Tracking

To evaluate the control system for the initial phase of the research, an acoustic transmitter was attached to a rope with an anchor and fixed 2 meters under the water's surface. The AUV started from several different locations around the tag. To evaluate the accuracy of the system, the GPS location of the acoustic tag was logged by a GPS device. Meanwhile the AUV was logging the path coordinates to evaluate the control system functionality afterwards. As it is presented on the figure 5.6 when LOTEK signal rate increases by the time, the standard deviation and error values decrease significantly. At the end of the mission, the standard deviation increases because of signal loss. Also, the cost function changes during the operations. As illustrated in figure 5.6, when the LOTEK signal rate increases by the time, cost function increases less than the time which the LOTEK signal rate decreases. To show this, derivative of cost function also is plotted in figure 5.6.

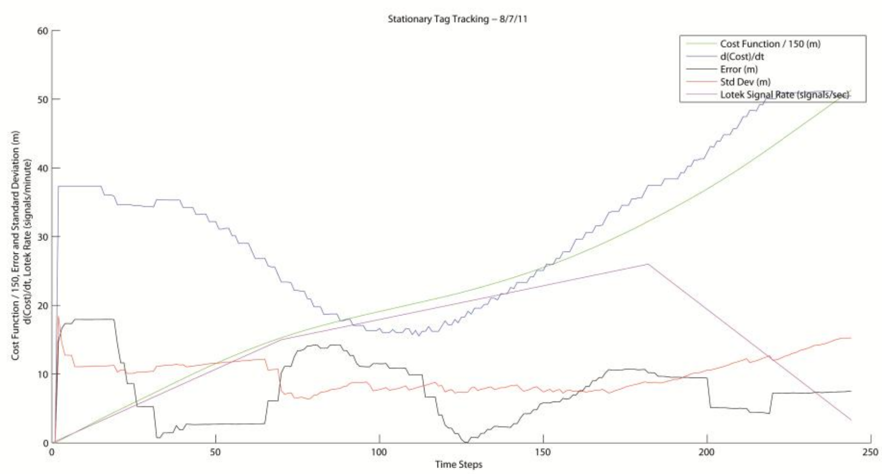


**Figure 5.6: Stationary Tag Tracking Plots.**

# 5.6.2. Tagged AUV Tracking

For the second round of experiments; the secondary AUV (IVER2) was tagged with an acoustic transmitter. Likewise the stationary tag tracking, the acoustic tag was attached to the AUV and fixed 2 meter under the water's surface.

This experiment was done in a longer duration due to a consistency check of the output results. In this experiment, data on the second AUV such as GPS logs and gyroscope (for heading bearing) logs were compared with the values which the follower AUV estimated about the second AUV. This comparison helps to calculate the error value. If the error value in a long duration mission was in a low range, the system would work well and would be ready to follow the shark promptly. As presented in the figure 5.7 in the beginning of the mission, the error value is lower in comparison with the second half of the mission. The high error value resulted from the area being covered with sea weed which acted like as a wall against acoustic signals and blocked them from the receiver. Therefore by having fewer signal rates, the error and standard deviation increased respectively until the AUV received a better signal rate. Similar to the stationary tag tracking results cost function increases less that than the time which the LOTEK signal rate increases and vice versa.

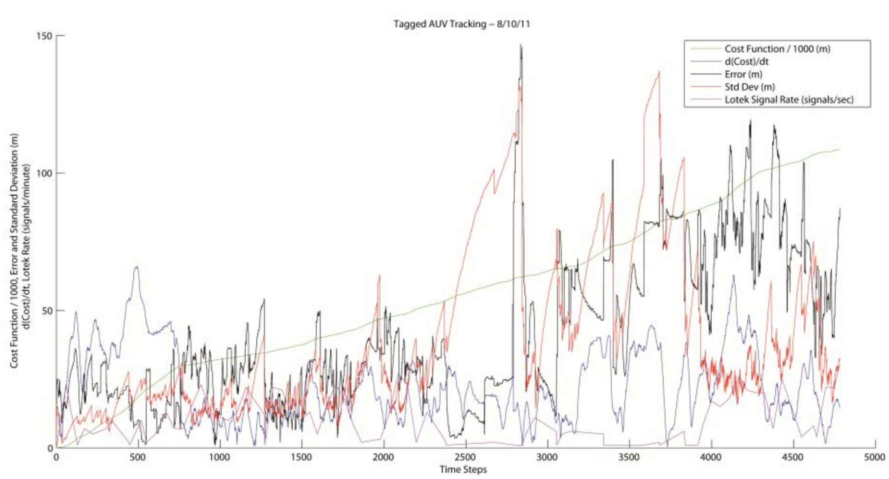


**Figure 5.7: AUV Tracking Plots.**

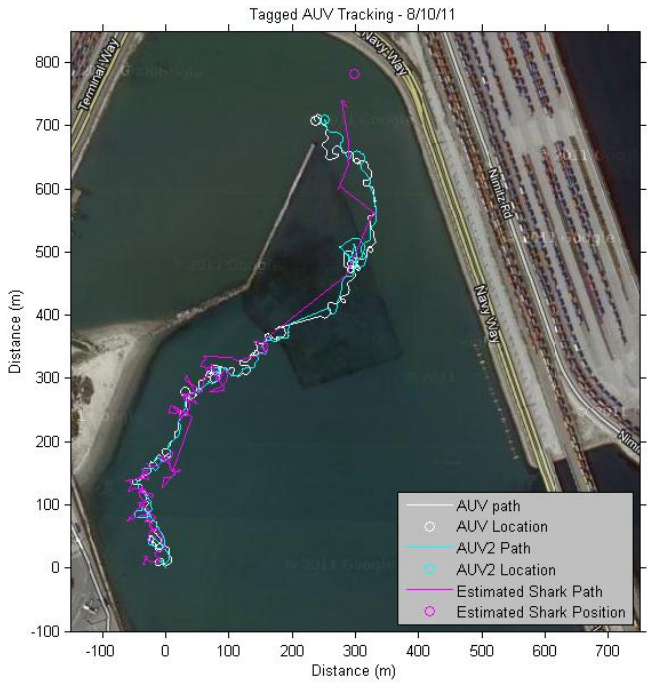


**Figure 5.8: AUV Tracking Path.**

### 5.6.3. Shark Tracking

When the results of the stationary tag and AUV tagged tracking were promising, the final phase of the research was planned to be done on a real shark. On August 2011, at SeaPlane Lagoon (located at Long Beach), a 2 meter leopard shark was lured and an acoustic transmitter was attached to its fin. Experiments took 3 days. A total of 36 hours of operation were performed by the AUV following the shark.

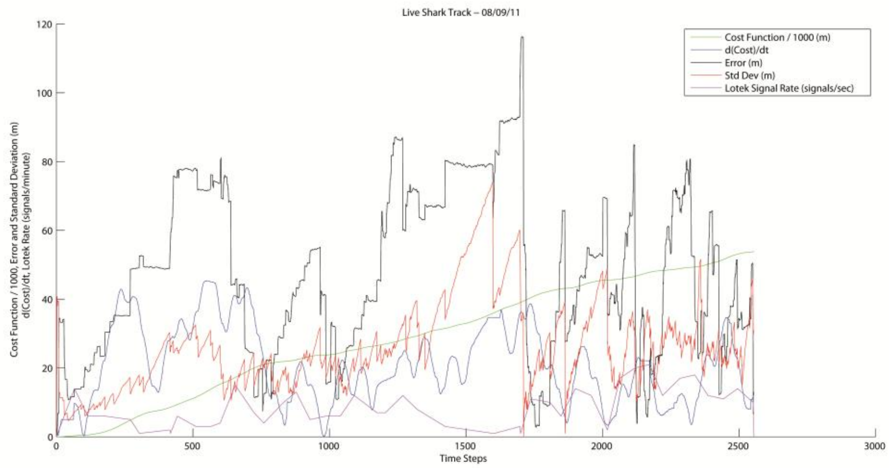


**Figure 5.9: Live Shark Tracking Plots.**

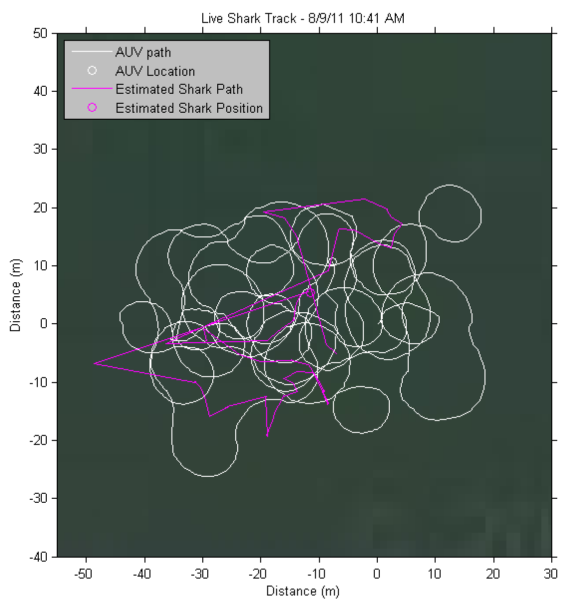


**Figure 5.10: Live Shark Path.**