ALFA Task 2 Deliverable M2.2.1: Underwater Vehicle Station Keeping Results

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1 Introduction

This document presents results testing the station keeping abilities of a tethered Seabotix vLBV300 underwater vehicle equipped with an inertial navigation system. These results are from an offshore deployment on April 20, 2016 off the coast of Newport, OR (44.678 degrees N, 124.109 degrees W). During the mission period, the sea state varied between 3 and 4, with an average significant wave height of 1.6 m. The vehicle utilizes an inertial navigation system based on a Gladiator Landmark 40 IMU coupled with a Teledyne Explorer Doppler Velocity Log to perform station keeping at a desired location and orientation. The data from the sensors are fused using an Extended Kalman Filter, and a feedback control system is used to maintain desired position and orientation. Streaming data is available to the operator in real time, and changes to the vehicle's desired position and orientation can be made on the fly. Additional details on the system can be found in the workshop publication [1].

During the deployment, station keeping was performed at two different times, denoted P2 and P3. At time P2, station keeping was performed at a depth of 10 meters where initially the vehicle was allowed to drift unpowered, and then station keeping was turned on to compare the two different responses. At time P3, station keeping was performed at the maximum depth for the deployment, defined to be approximately 5 meters of altitude from the seafloor, which corresponded to a depth of approximately 35 meters. Dive time was approximately 80 minutes total for the vehicle.

The rest of this report is organized as follows. Section 2 talks briefly about the data set and associated MATLAB code that will allow the user to investigate the data on their own. Section 3 reports the results for each of the station keeping test.

2 Data Set

The data set was obtained by parsing the command messages from the Greensea Integrated Navigational System which provided relative position and heading information. Each of the data files is a *.mat file which contains the following:

- x: the estimated relative x position measured from the desired position in meters
- y: the estimated relative y position measured from the desired position in meters
- z: the estimated relative z position measured from the desired position in meters
- heading: heading of the vehicle in degrees
- t_stamp: time at which the data is received in UNIX time

Provided with the data set is a MATLAB script to load the data and produce the graphs provided in this report. Additional detail is available in the provided README file. The MATLAB code and data set have been submitted for inclusion in the Department of Energy data repository.

3 Results

The results presented here report both the root mean squared error (RMSE) and the mean position error (ME) for station keeping at a location. Additionally, the RMSE and ME heading control for the vehicle is reported. Both P2 (10 m) and P3 (35 m) consisted of two different attempts at station keeping. For all positional graphs the green x shows the beginning, and the red circle shows the end of the data collection.

3.1 Summary of Results

The results demonstrate that the station keeping system produced mean position errors below 0.45 m and 2.5 m in the two 10 m depth trials, and mean errors below 0.6 m and 1.8 m in the two 35 m depth trials. The mean heading error was below 1.4 degrees and 15 degrees in each of the 10 m trials and below 2.3 degrees and below 5 degrees in each of the 35m trials.

The target values for this deliverable were less than 5 m error in position and less than 45 degree error in orientation in sea state 3 or above. These target values were met for both the 10 m and 35 m depth in sea states ranging from 3 to 4. The shallower depth showed somewhat higher errors, likely due to increased disturbances from ocean waves. Overall, these error values are sufficiently low for the intended goal of inspection and monitoring in wave energy arrays. Graphs showing the detailed results are presented below.

3.2 10 meter Depth

Figure 1 compares station keeping at 10 meter depth to approximately 200 seconds of drifting at the same depth. Figure 2 shows the position of the vehicle as it attempted to station keep at 10 meter depth in two trials for 151 and 86 seconds respectively. Figure 3 shows both the RMSE and ME error for all three directions as well as the overall error.

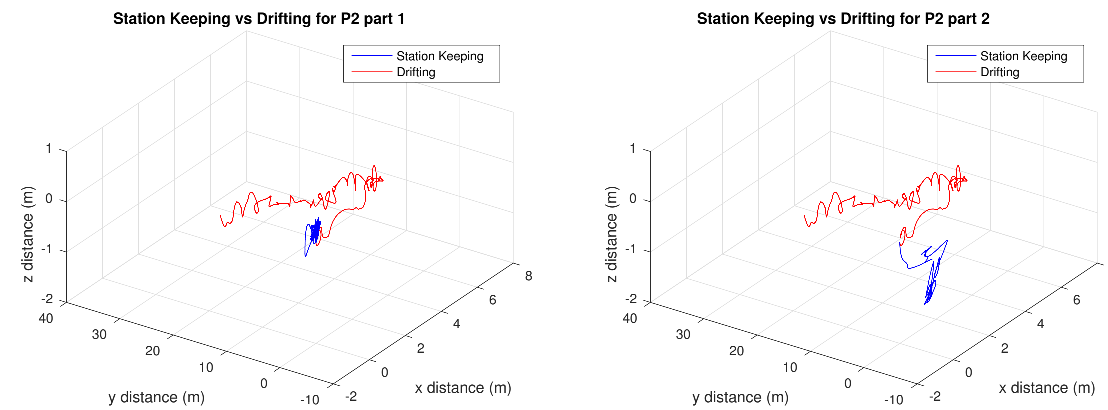

Figure 1: Comparison of station keeping versus drifting at 10 m depth (Left Trial 1: 200 seconds drifting and 151 seconds station keeping, Right Trial 2: 200 seconds drifting and 86 seconds station keeping)

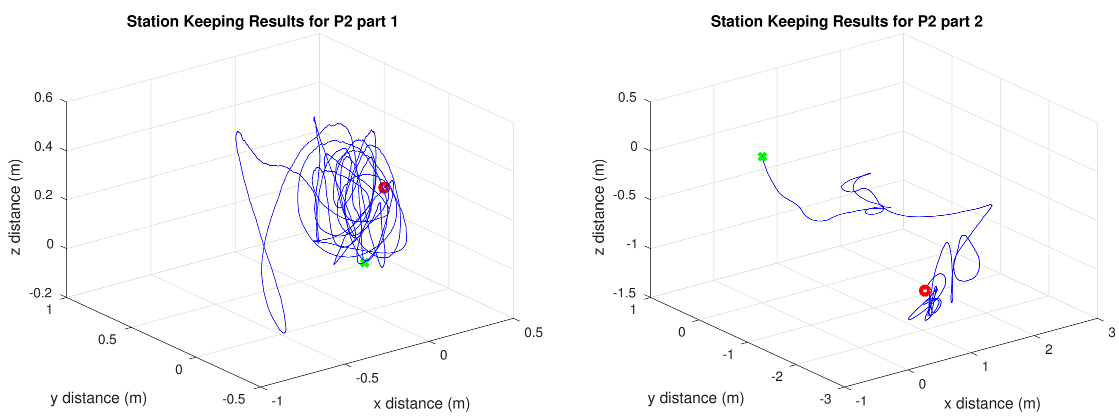

Figure 2: AUV Position Track for 10 m depth station keeping (Left Trial 1: 151 seconds, Right Trial 2: 86 seconds)

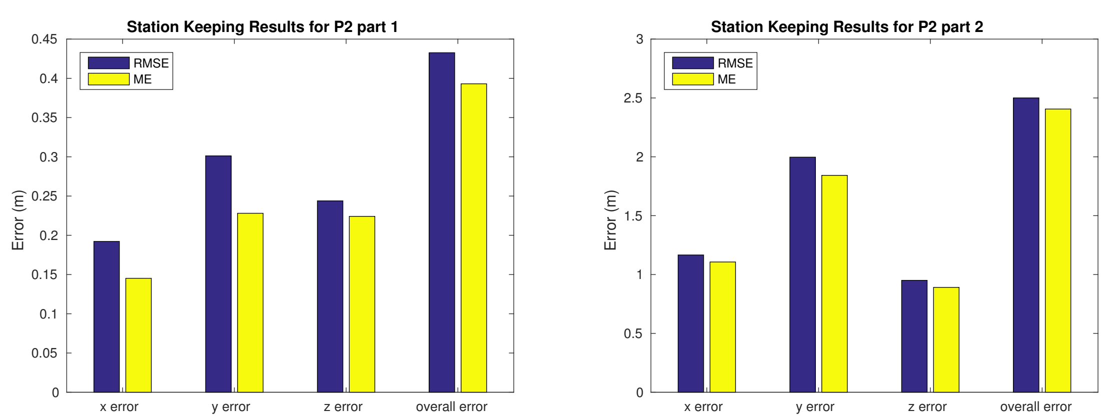

Figure 3: Root Mean Squared Error (RMSE) and Mean Error (ME) error for station keeping at 10 m depth (Left Trial 1: 151 seconds, Right Trial 2: 86 seconds)

3.3 35 meter Depth

Two different station keeping results are presented here for the 35 meter depth. Figure 4 shows the positional track of the vehicle as it performed station keeping for 72 and 186 seconds respectively. Figure 5 shows the RMSE and ME.

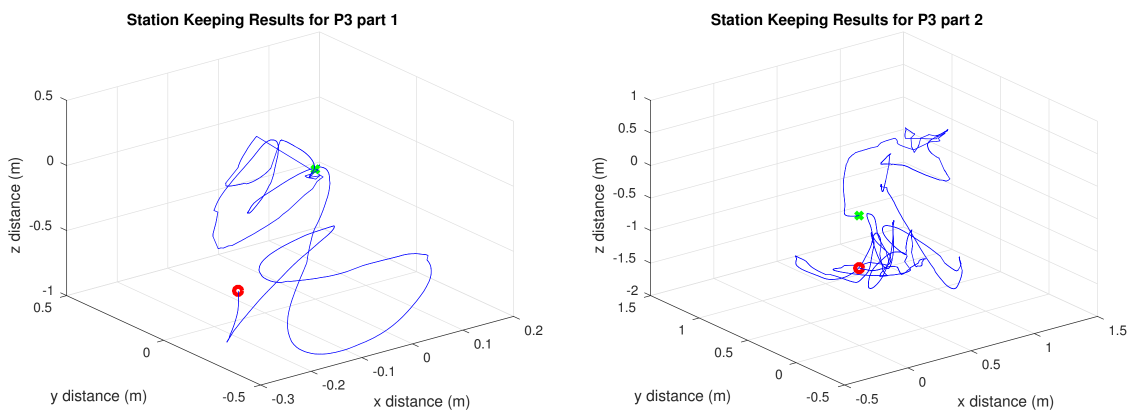

Figure 4: AUV Position Track for 35 m depth station keeping (Left Trial 1: 72 seconds, Right Trial 2: 186 seconds)

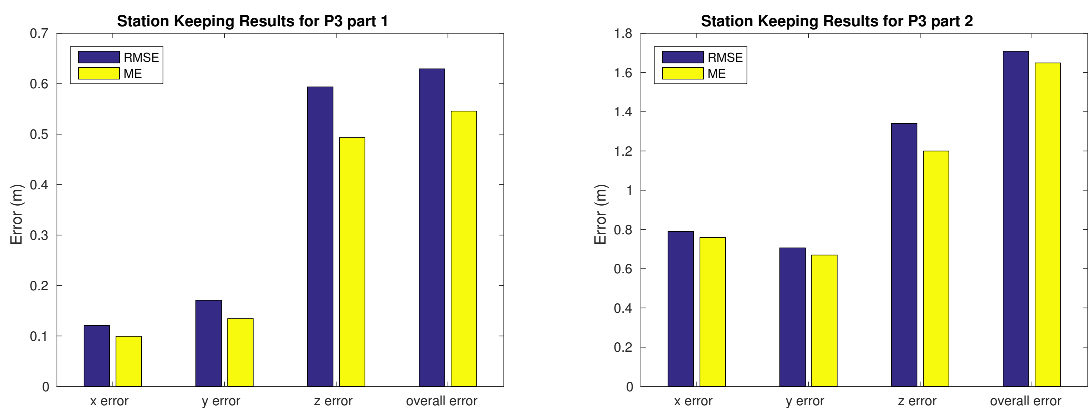

Figure 5: Root Mean Squared Error (RMSE) and Mean Error (ME) error for station keeping at 35 m depth (Left Trial 1: 72 seconds, Right Trial 2: 186 seconds)

3.4 Heading

Figures 6 and 7 show the RMSE and ME for the heading during station keeping. Each depth has one run where the error is very low and one run where the error is higher. This is due to an initial oscillatory behavior seen where if the vehicle was far from the desired heading the vehicle would overshoot when trying to correct and oscillate around the desired position. While this behavior would quickly disappear, this large initial error had an effect on the RMSE. In contract, the ME shows that this initial error was an outlier and the vehicle settled down to a controlled state quickly.

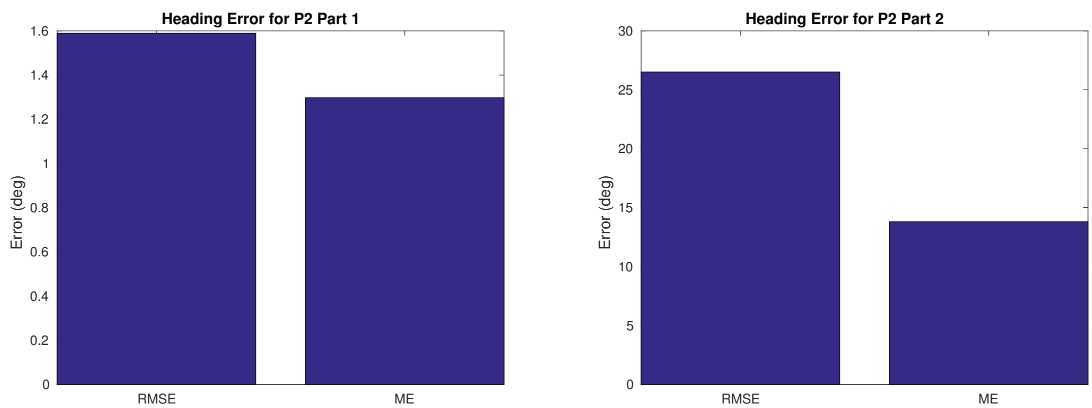

Figure 6: Heading error for P2 part 1 at 10 m depth (Left Trial 1: 151 seconds, Right Trial 2: 86 seconds)

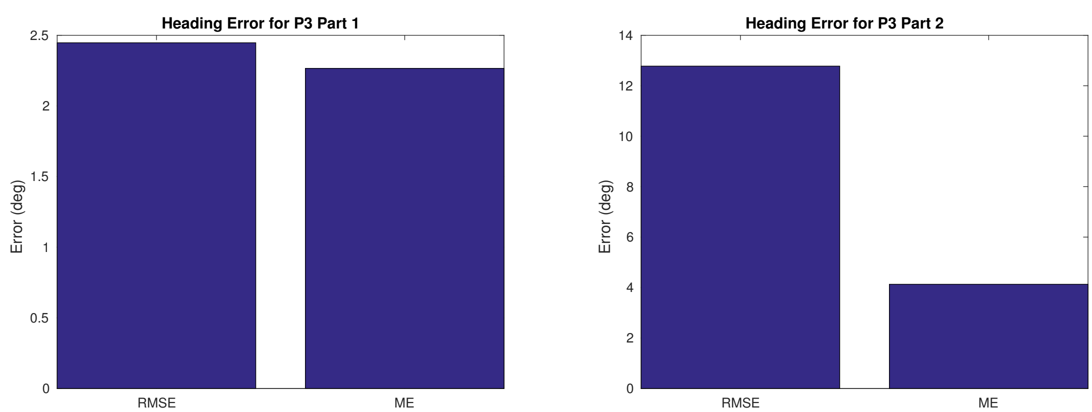

Figure 7: Heading error for P3 part 1 at 35 m depth (Left Trial 1: 72 seconds, Right Trial 2: 186 seconds)

References

[1] N. Lawrance, T. Somers, D. Jones, S. McCammon, and G. Hollinger. Ocean deployment and testing of a semi-autonomous underwater vehicle. In *Proc. IEEE Int. Conf. on Robotics and Automation Workshop on Marine Robot Localization and Navigation*, Stockholm, Sweden, May 2016.