A method for measuring navigation accuracy of submerged UUVs

Abstract — Navigation accuracy of a submerged unmanned undersea vehicle (UUV) is a vital component of mine warfare and surveillance missions which are increasingly being conducted by unmanned systems. The available methods for determining the position of an unmanned undersea vehicle (UUV) are numerous, but depend greatly on the depth of operation. GPS provides accurate position at the surface, and Doppler velocity log (DVL) sensors are very effective at improving dead-reckon positioning once the vehicle reaches a depth such that it can achieve bottom lock. In between, a number of off-board options exist to monitor the position of the UUV: imaging sonar systems, visual camera systems, and transponder positioning systems (long baseline, short baseline, or ultra-short baseline) being the most popular and plentiful. An overall methodology for assessing UUV navigation accuracy using fixed or mobile assets is proposed and explained. Experimental results of a subset of the methods described have been put into practice in recent experiments in California and Croatia. Preliminary results of these experiments will be presented.

1 Introduction

The aim of the Cooperative Unmanned Vehicles – Maritime Environment (CUV-ME) project is to provide, develop, integrate, and test the hardware and software protocols necessary to advance combined operations between multiple unmanned systems, to enhance the navigational accuracy of UUVs, and to improve the operational safety of operators engaged in unexploded ordnance remediation and counter underwater explosive operations. The Coalition Warfare Program, under the authority of the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, provided seed funding to this cooperative project between the University of Zagreb's Laboratory for Underwater Systems and Technologies (LABUST) and the Naval Information Warfare Pacific's (NIWC PAC's) Unmanned Maritime Vehicles Lab.[a]

This paper is organized as follows: Section 2 describes the plan and execution of the 2017 joint USA-Croatia sea trial. Section 3 provides a quick look of early results from that trial. Section 4 discusses improvements to be made in anticipation of the next sea trial, and Section 5 concludes and summarizes this paper.

2 2017 Sea Trial

The overall objectives of the two sea trials (one executed so far and one planned) under this agreement are far-reaching and varied. However, for the purpose of this document the relevant objective is a technique for measuring navigation accuracy of a submerged UUV which is consummate with the expected accuracy and repeatability of the system under test. The first of two sea tests was held at the Degaussing station near the Naval Base Lora in Split, Croatia, from 23 to 27 October 2017.

2.1 Test setup description

The general plan for the trial used a number of fixed and mobile assets to assess the navigation performance of a UUV under test. First, a reference line was placed on the bottom with the assistance of divers. To further mark the line visually, white square tiles (approximately 30 cm X 30 cm) were placed were placed periodically along the line. The nominal water depth in the trial area was approximately 10 meters. On clear and calm days, the reference line could be seen from the surface. In most trial conditions, it was visible to cameras when the underwater vehicles were operating at half the water depth (5 meters).

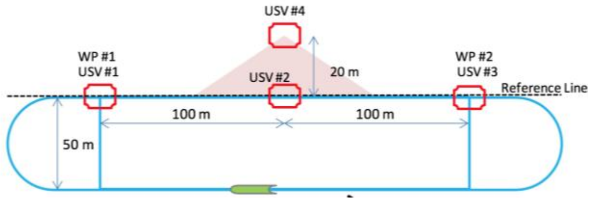

Fig. 1. Proposed Arrangement for measurement of Navigation Accuracy of UUV

As shown in Figure 1, the trial planned for three identical USVs in fixed positions above the reference line. The intended platforms for this application were the USV Proteus vehicles (see Fig.2b). [1] These vehicles were equipped with a downward looking HD camera, and a SeaTrac X150 USBL Beacon. They were put in a dynamic positioning (DP) mode to hold station above the intended track of the UUV under test. The fourth USV (a Marine Advanced Robotics WAM-V, see figure 2c) was intended to operate a short distance outside the racetrack pattern of the UUV, and operate a forward-looking sonar, a custom variant of the Teledyne BlueView M450 Series 2D multibeam imaging sonar, to view the UUV in passing the center of the reference line. The intention was to work with this fourth USV facing forward or sideways (in either case with the sonar pointing in the

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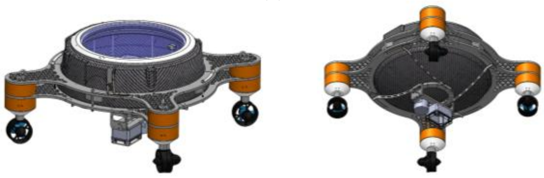
same direction) or possibly even moving at the same speed as the UUV to provide more continuous imagery near the center of the field of view.

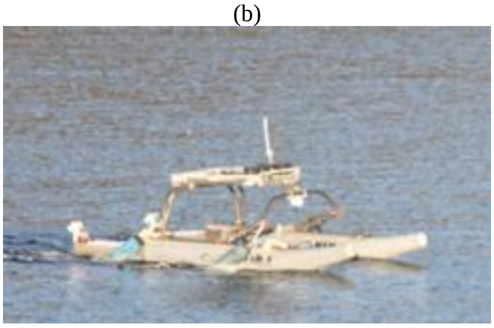
Two UUV systems scheduled for test in the first sea trial. These were the Lupis (see Fig.2a) which was equipped with an inertial measurement unit (IMU), compass, Doppler velocity log (DVL), and pressure sensor (PS) for localization. Additionally, it has a GPS unit, which it uses for localization while operating on the surface. The second UUV system was the Riptide MicroUUV, a simple, smaller, and low-cost alternative equipped with a compass unit, a pressure sensor and fathometer, but relying essentially on time/distance dead reckoning for horizontal positioning. Both UUVs were to be operated with a SeaTrac X010 USBL transponder in order to assess the improvement to be gained by the addition of a USBL system.

The UUV under test was planned to dive 5m deep (to be still visible in the USV camera at that depth) and transit the 200m long straight-line track. After each track, UUV resurfaced, and returned to the start of the track, doing so 5 times.

(a)



(b)



(c)

Fig 2. The vehicles used in the experiment. (a) UUV Lupis (b) Top and bottom view of the USV Proteus with camera and USBL mount. (c) Marine Advanced Robotics WAM-V, with BlueView sonar attached.

2.2 Execution of the trial

Logistical considerations precluded participation of the WAM-V from the first sea trial, but the associated electronics including the BlueView sonar were operated from a fixed platform approximately 20 meters away from the reference line in a nearly perpendicular direction (as was the intended position of USV #4 in figure 1). A specific instance of this test executed with the Lupis UUV was analyzed in detail, and the resulting data are published in [2] and summarized in the subsequent section.

3 First Results of the Trial

After completing the experiments, data sets of visual, sonar and USBL measurements were processed. Before using these raw measurements in the localization filter, they had to be preprocessed. The UUV's position measurements in the NE plane (with the well-tracked reference depth of 5m regarded as constant) were computed through coordinate frame transforms from automatic UUV detections in camera's pixel frame, USBL range and bearing measurements, as well as from manual UUV range and bearing detections in the sonar image. It has been shown that the USBL's range measurements were useful, while bearing measurements were unusable due to the huge amount of non-Gaussian noise.

3.1 Extended Kalman filter

The discrete kinetic model of the UUV with six degrees of freedom (6DOF) is used as a process model Extended Kalman Filter (EKF), consisting of the north, east, and heading states, as well as the surge, sway, and yaw rate velocities. Depth state of the UUV is neglected since the mission plan has ensured that the vehicle moves at the desired depth during its set linear track. Zero dynamics of velocities is added to the model, so velocity estimation is enabled through perturbation of measurements and EKF process noise parameters. The basic EKF measurement model uses dead reckoning to localize the UUV, and it is augmented whenever GPS, and/or camera, and/or sonar, and/or USBL measurements are available

3.2 Results

A performance comparison of the EKFs with various available measurements is shown in Fig. 3 for one of the 5 straight line tracks paths that the UUV was following underwater. It can be noted that with each augmentation of the localization filter with new available measurements, its performance improves, i.e. the closer the UUV's estimated position is to the first stable GPS fix when it resurfaces.

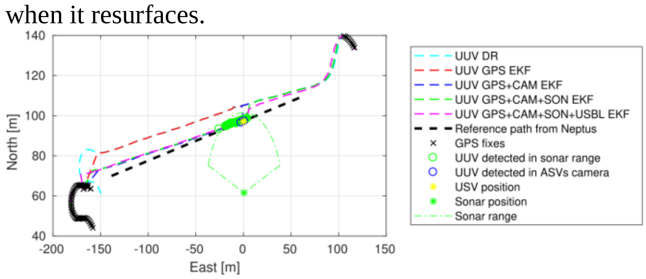


Fig. 3: An example of the implemented EKF localization of the UUV with different measurements available. Start of the UUV traversing the transect is in the top right, while the end of the transect is at the bottom left end of the transect.

The aggregated results comparing all steps of EKF augmentation with different measurements for UUV's localization improvement for all 5 transects are given in Table I. The performance measure used for comparing the above described EKF approaches is determined as the distance of the estimated UUV's position from the first stable GPS fix in the moment after the UUV resurfaces. It can be noted that with the gradual augmentation of the EKF its performance becomes better. It is interesting to note that adding range-only USBL measurements improved the performance of the EKF in 40% of the cases. However, when comparing camera, sonar, and USBL-augmented to dead reckoning (DR) localization, and EKF with GPS fixes, the improvement of the proposed approach is 40-69%, and 33-65%, respectively, which represents a significant improvement.

Table I: Aggregated performance of the EKF localization improvement for 5 transects each of which was 200m long. Performance measure: the distance in meters of the estimated UUV's position from the first stable GPS fix after resurfacing.

	#1	#2	#3	#4	#5
DR	27.15	28.29	25.99	33.35	18.96
GPS EKF	24.76	24.0	23.1	31.3	18.8
GPS+CAM EKF	18.1	20.3	20.1	21.0	18.75
GPS+CAM +SON EKF	14.12	16.05	13.55	16.65	6.24
GPS+CAM +SON +USBL EKF	13.89	16.07	8.10	17.57	11.25

4 Future Plans

The following are the among the advances that have been made in preparation for the second sea trial, now tentatively planned for September of 2019

4.1 Alternate UUV configurations

Reliability problems plagued our efforts to make progress on navigation measurements and autonomy development with the Riptide MicroUUV vehicles. An alternative platform was identified in the BlueRobotics BlueROV. Researchers at NIWC-Pacific have modified the intended tethered configuration and operated the platform via teleoperation via wifi when surfaced and autonomously including submerged missions of arbitrary time duration. While the MicroUUV maintains advantages of speed and lower drag configuration that will be important in high current situations, the BlueAUV, as our modification is called, is a viable alternative in many situations. By using a modular software architecture, advances in one vehicle can translate directly to the another with minimal rework and customization.

4.2 Alternate USV configurations

In keeping with the idea of modular software architecture opening the door to alternative platforms, a smaller catamaran vessel has been prototyped at NIWC-Pacific. This vessel, named SUTIS, employs a smaller thruster design, a lower payload platform, and hull length of just under 2 meters. The result is a vessel that three persons can carry and launch, eliminating the need for a trailer or crane for deployment. In protected waters inside a harbor, this is an appropriate design tradeoff.

4.3 Alternate USBL suppliers

Although the SeaTrac USBL transducers are among the smallest on the market and provide good range accuracy, alternatives are being considered. Especially interesting are units that might provide more consistent bearing measurements in difficult shallow water reverberant environments.

5 Conclusion

This paper has outlined a general methodology for measurement of navigation accuracy of a submerged UUV. Specific instances of this methodology were executed in late 2017, and initial results have been analyzed and published. A glimpse of future plans for the next trial was provided with some important improvements and diversity in approaches. The authors look forward to one or more future cooperative trials.

References

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[2] N. Kapetanović, Đ. Nađ, N. Mišković and Z. Vukić, "Towards Enhancing the Navigational Accuracey of UUVs Through Collaboration of Multiple Heterogeneous Marine Vehicles," in Proc. IEEE OES UAV2018 Symposium,, Porto, Portugal, 2018.

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Thomas Pastore has been employed by the Naval Information Warfare Center - Pacific and predecessor organizations for more than 30 years. His major contributions to the organization have been advances in technology for port protection and harbor defense systems. Specific technology areas of interest and expertise include underwater acoustics, communications and networking, as well as unmanned autonomous systems.

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