ID24- AUV/ASC COOPERATIVE SURVEY

NARCÍS PALOMERAS[203], NATALIA HURTÓS[204], MARC CARRERAS[202]

Abstract – In this paper we describe a solution to perform autonomous surveys taking advantage of a cooperative multivehicle setup. In the proposed configuration, an ASC provides –through an USBL- absolute positioning and communications to an AUV. Thus, by following the AUV with the surface vehicle we facilitate the reception of USBL measurements in the AUV regardless of the extent of the mission. This turns into an improved navigation on the AUV's side, with the drift bounded thanks to the absolute measurements. Experimental results show that the proposed algorithm is able to maintain the ASC at a close distance and improve the navigation of the AUV. Moreover, the bathymetric maps built from the AUV data are consistent enough to enable the automatic detection of present targets and program further localized missions in the area.

Keywords – cooperative navigation, autonomous survey, multiple vehicles, localization.

I. INTRODUCTION

The Spanish funded project MERBOTS [1] aims to push forward the development of underwater intervention systems. To that end, it involves the use of multi-robot cooperation and multimodal perception systems in the context of archaeological missions. The project divides underwater interventions in two main stages. The first stage is implemented with an autonomous underwater vehicle (AUV) equipped with acoustic and optical sensors and an autonomous surface craft (ASC) whose goal is to localize the AUV acoustically and enable its communication with a remote base. This configuration is used to produce an acoustic map on which a set of targets can be automatically detected and then, generate and execute a second survey, at a closer range using optical sensors. The second stage consists in the actual intervention operation, which is carried out by a hybrid remotely operated vehicle (H-ROV) with an electric manipulator and an AUV equipped with cameras that support the HROV operation providing images from an external viewpoint. This paper focuses on the first stage, more specifically, on the cooperative survey where the AUV performs a pre-planned trajectory underwater while the ASC is following it at surface.

Standard navigation sensors for underwater vehicles include Doppler velocity log (DVL) to measure linear velocities, attitude heading reference system (AHRS) to measure orientations and angular velocities and pressure sensors to measure depth. The lack of absolute measurements to estimate the AUV north-east position causes the vehicle to drift over time. To avoid this problem several techniques can be used: surface the vehicle regularly to obtain GPS updates, install several long baseline (LBL) buoys or use a USBL system are amongst the most popular. While the first one is the most affordable it is clearly the less convenient. The LBL system is expensive and difficult to install. On the other hand, the USBL main drawback is that, in order to obtain accurate measures, the AUV has to navigate inside the cone described by the USBL transceiver, which can become a problem if the survey area is shallow or relatively large. To solve this problem and allow real-time communication between a remote base and the submerged AUV we propose a cooperative AUV/ASC setup. Instead of the typical USBL installation in a buoy, an ASC will be used to follow the AUV without any a priori knowledge of the trajectory to be performed. Section II describes the navigation filter implemented in both the AUV and the ASC. The tracking algorithm executed by the ASC is detailed in Section III. Section IV reports the experiments performed in a harbour environment to test the proposed approach and Section V summarizes the main conclusions.

II. NAVIGATION

Both vehicles use the same extended Kalman filter (EKF) for navigation. The proposed state vector is xk=[x, y, z, u, v, w]T where [x, y, z] is the vehicle position (in world coordinates) and [u, v, w] are the linear velocities (with respect to the vehicle's frame). Vehicle orientation is not estimated by the filter, however, it is used as an input in the EKF. The filter uses a constant velocity model and it is able to receive four different measurement updates: velocities [u, v, w], depth [z], position [x, y] and delayed position [x, y]. It is important to differentiate between delayed (USBL) and not delayed (GPS) position updates. While GPS measures are introduced in the filter on-time, the USBL measures are gathered by the ASC through the USBL and sent to the AUV using the acoustic modem thus adding a significant delay (i.e., between 2 to 10 seconds). Therefore, the filter must be able to deal with these delayed positions. Figure 1 shows the measurement updates available in each vehicle. Notice that, although the filter is the same, the updates are significantly different. While the AUV has DVL, GPS, depth sensor, AHRS and USBL updates, the ASC only has GPS and AHRS. However, the revolutions per minute (RPM) that the controller sends to the thrusters are used to estimate its velocity.

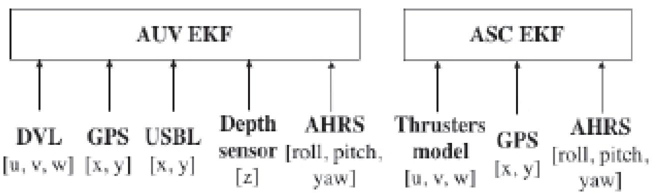

Fig 1. AUV and ASC navigation sensors and EKF

III. ASC TRACKING ALGORITHM

In the proposed cooperative survey scenario, the AUV starts following a predefined trajectory at a certain altitude and the ASC must follow it automatically. In order to provide the maximum number of USBL updates to the AUV navigation filter, the ASC must be located as close as possible to the AUV vertical. Besides, due to the limited acoustic modem bandwidth, the tracking algorithm must be able to work with restricted communications between the ASC and the AUV. In view of these requirements, the following procedure has been implemented:

· When the ASC detects the AUV position with the USBL, it navigates towards this position and sends this information to the AUV using the modem.

· Every time that the AUV receives a USBL update it updates its filter and replies the ASC with the current goal position.

· If the ASC receives the goal position where the AUV is navigating to, it computes how to intercept the AUV knowing its own position, the last AUV position obtained with the USBL and the goal position (see Algorithm 1).

· If the AUV is already over the AUV and it knows where the AUV is going it sets the same goal position but in surface.

Algorithm 1 shows how to compute the interception point knowing the AUV and ASC positions, the average velocities of both vehicles and the position where the AUV is navigating to (goal).

```
function intercept(AUV, ASC, goal)
  angle = atan2(goal.x - AUV.x, goal.x - AUV.x)
  v.x = cos(angle)*AUV.surge
  v.y = sin(angle)*AUV.surge
  t.x = AUV.x — ASC.x
  t.y = AUV.y — ASC.y
  a = v.x^2 + v.y^2 — ASC.surge^2
  b = 2*(v.x*t.x + v.y*t.y)
  c = (t.x)^2 + (t.y)^2
  ti = (-b - sqrt(b^2-4*a*c)) or (-b - sqrt(b^2+4*a*c))
  return [ASC.x + v.x*ti, ASC.y + v.y*ti]
```

Algorithm 1. Compute interception point

IV. RESULTS

The proposed cooperative survey mission has been tested in Sant Feliu harbour (Spain). The AUV vehicle has been a Sparus II AUV [2] equipped with an Imagenex multibeam sonar, an optical camera and an Evologics modem as well as an AHRS, a DVL, a depth sensor and a GPS to initialize the filter. The ASC role has been played by a Girona 500 AUV [3] equipped only with an AHRS, a GPS and an Evologics USBL.

Sparus II AUV has been commanded to follow a lawnmower trajectory. Figure 2 shows the trajectory performed by both vehicles. It can be seen how not all the USBL measurements are correctly transmitted to the AUV due to modem communication failures. Figure 3, shows the distance between both vehicles over time. Notice that this distance is in average below 5 meters in the north-east plane except between seconds 400-500 where several outlier USBL measurements have moved the ASC incorrectly (position 20, 0 in Fig. 2).

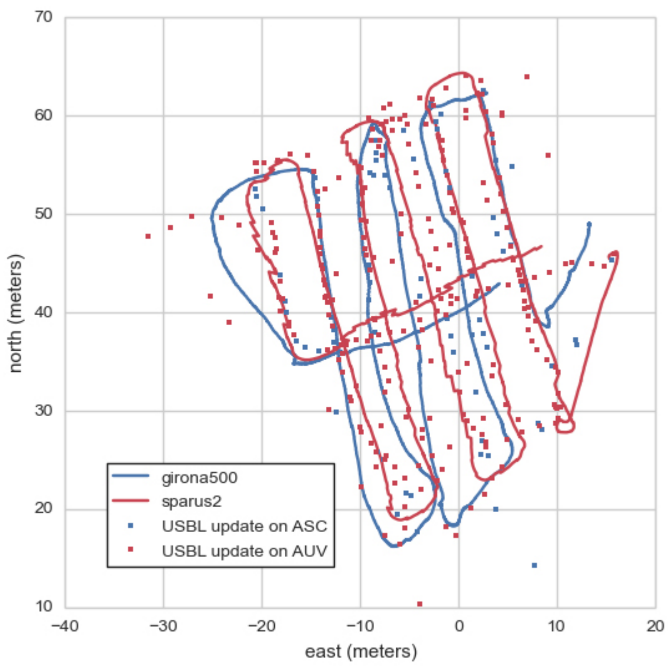

Fig 2. AUV and ASC autonomous trajectories

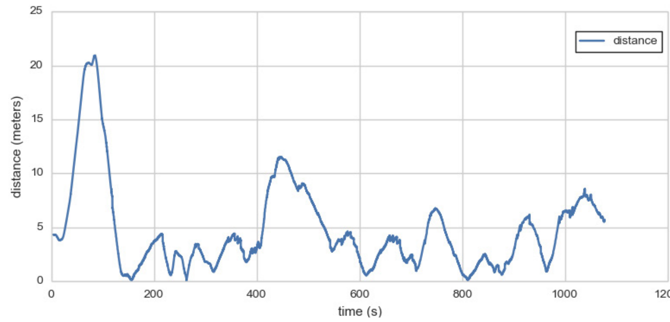

Fig 3. Euclidean distance between AUV and ASC over the whole mission

It is possible to check that, thanks to the USBL updates, the AUV navigation presents almost no drift. We have built the bathymetry of the multibeam data gathered along the lawnmower trajectory (see Fig. 4a) and we can observe how the resulting map is consistent (i.e., the objects that are visible in more than one transect are consistently mapped). Furthermore, we can see how the resulting bathymetry matches almost perfectly a previous bathymetry obtained with an RTK GPS (Fig. 4b).

V. CONCLUSIONS

This paper has presented a cooperative setup in which an ASC provides absolute localization and communications to an AUV while performing and autonomous mission. Using a minimal sensor suite, the AUV has been capable to perform a trajectory keeping its drift bounded. This improvement in the navigation enables the generation of consistent maps and will enable the AUV to accurately revisit detected targets in an automated way. As a future work we are working to filter the USBL data in the interception algorithm to avoid outlier measurements as well as to complete the automatic target detection and inspection.

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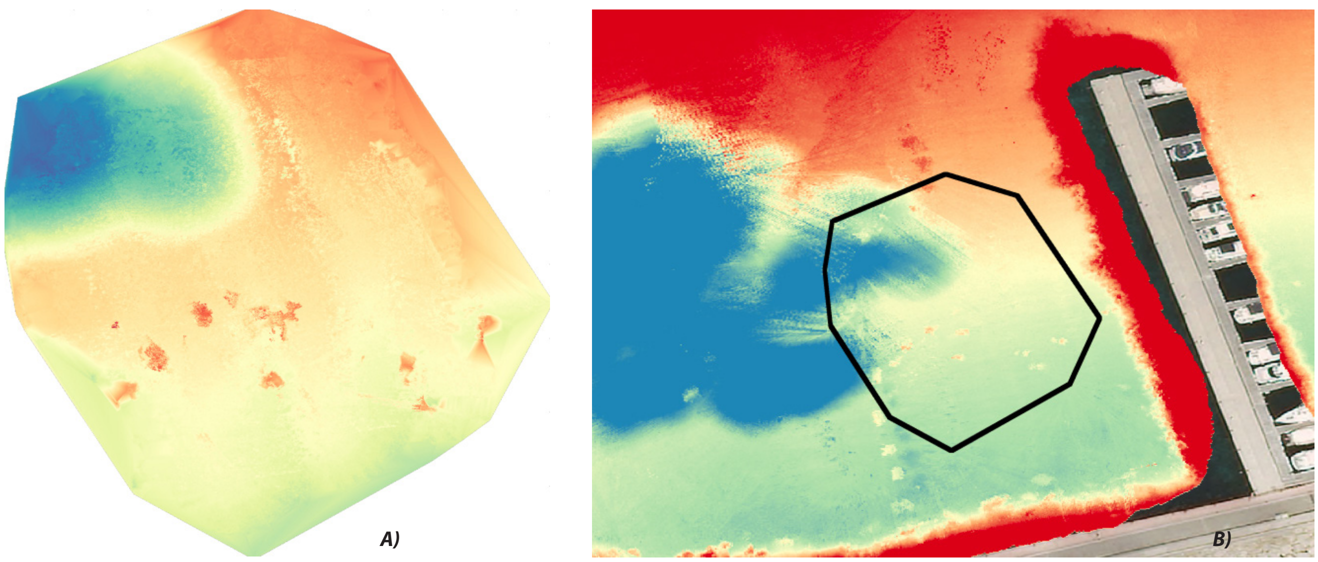

Fig 4. a) Bathymetry generated from the multibeam data gathered by Sparus II data while navigating