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Development of a Navigation Algorithm for Autonomous Underwater Vehicles

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Abstract: In this paper, the authors present an underwater navigation system for Autonomous Underwater Vehicles (AUVs) which exploits measurements from an Inertial Measurement Unit (IMU), a Pressure Sensor (PS) for depth and the Global Positioning System (GPS, used during periodic and dedicated resurfacings) and relies on either the Extended Kalman Filter (EKF) or the Unscented Kalman Filter (UKF) for the state estimation. Both (EKF and UKF) navigation algorithms have been validated through experimental navigation data related to some sea tests performed in La Spezia (Italy) with one of Typhoon class vehicles during the NATO CommsNet13 experiment (held in September 2013) and through Ultra-Short BaseLine (USBL) fixes used as a reference (ground truth). Typhoon is an AUV designed by the Department of Industrial Engineering of the Florence University for exploration and surveillance of underwater archaeological sites in the framework of the Italian THESAURUS project and the European ARROWS project. The obtained results have demonstrated the effectiveness of both navigation algorithms and the superiority of the UKF (very suitable for AUV navigation and, up to now, still not used much in this field) without increasing the computational load (affordable for on-line on-board AUV implementation).

Keywords: Autonomous Underwater Vehicles (AUV), Navigation, Ultra-Short BaseLine (USBL), Unscented Kalman Filter (UKF), Extended Kalman Filter (EKF)

1. INTRODUCTION

In this paper, the authors present an navigation system specifically designed for AUVs and its experimental evaluation in typical underwater missions. The developed system exploits inertial sensors (IMU), depth sensors and GPS fixes (during periodic resurfacing) and relies on the Unscented Kalman Filter (UKF) (Julier and Uhlmann (2004), Wan and Merwe (2001), Ristic et al. (2004)) for motion estimation. The proposed navigation system has been experimentally validated through navigation data related to sea tests performed in La Spezia (Italy) with the Typhoon AUV (see Fig. 1, (Allotta et al. (2014a), Allotta et al. (2014b))) in the framework of the Italian THESAURUS project (Allotta and Caiti (2014)) and the European ARROWS project (Allotta (2014)) during the NATO CommsNet13 experiment (Potter (2014)), in September 2013. Typhoon is an AUV designed by the Department of Industrial Engineering of the Florence University for exploration and surveillance of underwater archaeological sites. Currently two versions of the Typhoon AUV have been built, characterized by dfferent sensors and payloads. The vehicles are named TifOne and TifTu respectively. The test campaign described in this paper has been performed using TifTu vehicle equipped with a sensor set including an IMU (with 3D accelerometer, gyroscope and magnetometer), pressure sensor for the depth, GPS and USBL.

Fig. 1. The Typhoon AUV during the sea tests in La Spezia (Italy).

The experimental measurements taken with TifTu AUV include the sensor data concerning the vehicle dynamics (IMU and pressure sensor), global positioning system

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(GPS) fixes obtained through periodic and dedicated vehicle resurfacing (Yun and Bachmann (1999), Marco and Healey (2001)) and global positioning provided by the USBL and obtained thanks to the permanent testbed for underwater networking and communication purposes (LOON - Littoral Ocean Observatory Network) of the Center for Maritime Research and Experimentation (CMRE, formerly NURC). The USBL fixes are not exploited by the new navigation system, being only used as a reference (ground truth) to evaluate the algorithm accuracy.
At this initial stage of the research activity, the experimental underwater test has been performed with the AUV autonomously navigating in dead reckoning along a triangle-shaped path. To effectively evaluate the navigation system performance, the validation has been performed offline, applying the new navigation system to experimental data measured on the vehicle navigating in dead reckoning.
A performance comparison between the proposed UKF-based navigation system and a standard EKF- based system (Allotta et al. (2012)) has been carried out. The comparison allowed the authors to evaluate the accuracy of the proposed navigation approach (very suitable for AUV navigation and, up to now, still not used much in this field) in estimating the vehicle dynamic behaviour without increasing the computational load (affordable for on-line on-board AUV implementation).

2. GENERAL ARCHITECTURE

The typical test architecture is schematized in Fig. 2.

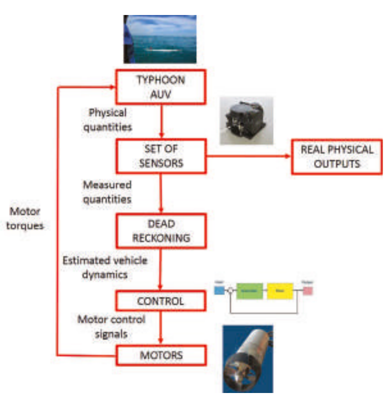

Fig. 2. Online testing of navigation systems.

The Typhoon AUV navigates in dead reckoning using the information coming from the available sensors. The physical quantities characterizing the Typhoon AUV dynamics (orientation, depth and position) are measured by the set of on-board sensors. The measured quantities are then processed in dead reckoning to approximately estimate the vehicle dynamics. Starting from the estimated vehicle dynamics, the control is able to calculate the motor control signals (Allotta et al. (2012)). Finally, the thrusts produced by the motors allow the vehicle to follow the desired dynamics.
The sensor suite provides the real physical outputs to be used to test and compare the different navigation systems (i.e., the EKF-based and UKF-based ones). The preliminary validation and analysis of the navigation system presented by the authors in this work are performed offline. The adopted architecture for offline testing is depicted in Fig. 3.

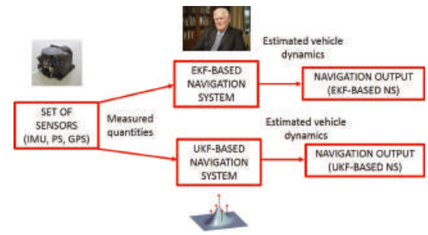

Fig. 3. Offline testing of navigation systems.

The test of the navigation system relies on the data measured by the sensor suite (IMU, pressure sensor and GPS during periodic resurfacings). The measured quantities (orientation, depth and position) are processed by both EKF and UKF algorithms in order to recursively generate estimates of the AUV state. Then, such estimates are compared to the USBL position fixes during the whole mission.

3. THE TYPHOON AUV

In this chapter, the main parts of the Typhoon AUV architecture for the testing of navigation systems are described.

3.1 The vehicle

Typhoon is a middle-sized AUV able to reach a 300 $[m]$ depth. The vehicles can carry suitable payload for the specific underwater mission to perform. Currently, two Typhoons AUVs are fully operative and already performed many missions at sea: the vehicles are called TifOne and TifTu.
TifTu, the AUV exploited during the CommsNet13 sea campaign (Potter (2014)), has a length of 3700 $[mm]$, an external diameter of 350 $[mm]$ and a weight of about 150 $[kg]$ according to the carried payload (the vehicle can be considered an intermediate one compared to the smaller Remus 100 (Packard et al. (2013)) and the bigger Remus 600 (Stokey et al. (2005))). Its autonomy is $8 - 10\,[h]$ and the maximum reachable longitudinal speed is 6 $[kn]$ (whereas the cruise speed is about 2 $[kn]$). The power needed by the propulsion on-board systems and payloads was approximately known (about 350 $[W]$): considering a mission duration of about $8 - 10\,[h]$, the needed energy was calculated in about $3 - 3.5\,[kWh]$. Li-Po (Lithium-Polymer) batteries have been chosen.
In Fig. 4, both the Typhoon CAD design and its final built versions can be seen.

TifTu propulsion system is composed of 6 actuators: two lateral thrusters, two vertical thrusters and two main rear propellers (both working in longitudinal direction). The propulsion system actively controls 5 Degrees Of Freedom (DOFs) of the vehicle (the only one left passive is the roll one).