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A new AUV navigation system exploiting unscented Kalman filter

B. Allotta [a,c], A. Caiti [b,c], R. Costanzi [a,c], F. Fanelli [a,c], D. Fenucci [b,c], E. Meli [a,c,*], A. Ridolfi [a,c]

[a] *Mechatronics and Dynamic Modelling Laboratory - MDM Lab, Department of Industrial Engineering Florence - DIEF, University of Florence, Via di Santa Marta 3, 50139 Florence, Italy*
[b] *Bioengineering and Robotics Research Center, Centro Piaggio, University of Pisa, Largo Lucio Lazzarino 1, 56122 Pisa, Italy*
[c] *Interuniversity Center of Integrated Systems for the Marine Environment (ISME)[1], Italy*

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ABSTRACT

The development of precise and robust navigation strategies for Autonomous Underwater Vehicles (AUVs) is fundamental to reach the high level of performance required by complex underwater tasks, often including more than one AUV. One of the main factors affecting the accuracy of AUVs navigation systems is the algorithm used to estimate the vehicle motion, usually based on kinematic vehicle models and linear estimators. A precise and reliable navigation system is indeed fundamental to AUVs: the Global Positioning System (GPS) signal is not available underwater, thus making it very hard to know the position of the vehicle in real-time. In this paper, the authors present an innovative navigation strategy specifically designed for AUVs, based on the Unscented Kalman Filter (UKF). The new algorithm proves to be effective if applied to this class of vehicles and allows us to achieve a satisfying accuracy improvement compared to standard navigation algorithms. The proposed strategy has been experimentally validated using the navigation data acquired in suitable sea tests performed in Biograd Na Moru (Croatia) in the framework of the FP7 European ARROWS project tests performed during the Breaking the Surface 2014 (BtS 2014) workshop. The vehicles involved are the two Typhoon AUVs, developed and built by the Department of Industrial Engineering of the University of Florence within the THESAURUS Tuscany Region project for exploration and surveillance of underwater archaeological sites. The experiment, described in the paper, was performed to preliminary test the cooperative navigation between these AUVs. The new algorithm has been initially tested offline, and the validation of the proposed strategy provided accurate results in estimating the vehicle dynamic behaviour.

1. Introduction

Nowadays, Autonomous Underwater Vehicles (AUVs) are widely used in many fields of application: they are employed for scientific purposes (e.g. exploration and surveillance of archaeological sites), to complete industrial tasks at high depths (for instance they are exploited in the Oil&Gas industry), to carry out reconnaissance and patrolling missions in the military field, or even to conduct search and rescue duties.

Regardless of the kind of mission the vehicle is required to execute, the availability of a precise and robust navigation system, i.e. suitable hardware and software components used to estimate in real-time the vehicle pose, is of fundamental importance (Fossen and Ocean, 1994; Siciliano and Khatib, 2008; Antonelli, 2006; Caffaz et al., 2010). Indeed, the high accuracy needed by the imposed tasks, which can even involve multiple vehicles (Allotta et al., 2015a; Breivik and Fossen, 2005; Petres et al., 2007; Fjellstad and Fossen, 1994) makes motion estimation a key factor in underwater autonomous navigation, requiring precise and computationally lightweight estimation algorithms. The quality of the navigation system not only influences the results of the performed mission in terms of position error between the desired and the executed path, but also affects the outcome of the georeferencing process of the data acquired by the onboard sensors; this is especially important in archaeology, history or anthropology-related missions (e.g. the exploration of ancient wrecks).

In addition to the intrinsic difficulties of the localisation task, the underwater environment poses additional limitations that further complicate the estimation process: for instance, the Global Positioning System (GPS) signal is not available underwater,

* Corresponding author.
E-mail addresses: benedetto.allotta@unifi.it (B. Allotta), andrea.caiti@dsea.unipi.it (A. Caiti), riccardo.costanzi@unifi.it (R. Costanzi), francesco.fanelli@unifi.it (F. Fanelli), d.fenucci@gmail.com (D. Fenucci), enrico.meli@unifi.it (E. Meli), a.ridolfi@unifi.it (A. Ridolfi).

[1] URL: www.isme.unige.it

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Fig. 1. The Typhoon AUVs performing sea tests in Biograd Na Moru (Croatia) during BtS 2014.

making it very hard to estimate the vehicle position. This increases the need for a precise and robust navigation system.

The vast majority of the motion estimation filters which are used is based on the Kalman Filter (KF) (Kalman and New, 1960) and on the Extended Kalman Filter (EKF) (Bar-Shalom et al., 2001; Evensen, 2009; Sayed, 2008; Allotta et al., 2012, 2015a), a KF extension which can be employed on nonlinear dynamical systems. Furthermore, such filters usually make use of simplified kinematic and dynamic models of the vehicle; such models must indeed offer a good trade-off between the accurate reproduction of reality and the demand for computational resources, in order to be used in real-time within an estimation filter without simplifying too much the physical behaviour of the AUV.

In this paper, a new motion estimation algorithm is proposed; the algorithm is based on the Unscented Kalman Filter (UKF) (Julier and Uhlmann, 1997; Wan and Merwe, 2001; Ristic et al., 2004), and it is specifically designed for AUVs, exploiting the data acquired by the available onboard sensors, including inertial, linear velocity, acoustic and depth sensors (Arrichiello et al., 2011; Bahr et al., 2009a; Bhar et al., 2009b; Larsen, 2000; Rigby et al., 2006). The Unscented Kalman Filter offers a convenient trade-off between performance and computational load but, to the best of authors' knowledge, it has not yet been extensively used in practical underwater applications.

Particular effort has been dedicated to the development of a suitable model of the AUV, accurate enough to produce consistent results when used within a recursive estimation filter, but not too demanding in terms of required computational load.

At this initial phase of the research activity, a preliminary validation of the proposed filtering algorithm has been executed offline on the data acquired by the two Typhoon AUVs, developed and built by the Department of Industrial Engineering of the University of Florence in the framework of the Tuscany Region

Table 1
Typhoon AUV physical data and performance.

Typhoon AUV characteristics	
Length (mm)	3600
External diameter (mm)	350
Mass (kg)	130–180 (dep. on payload)
Max speed (kn)	5–6
Max depth (m)	300
Autonomy (h)	> 8

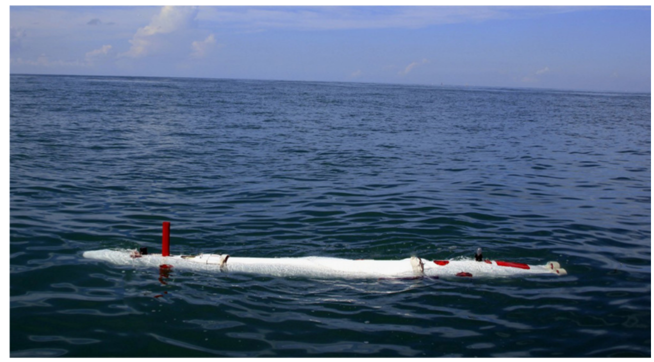

Fig. 2. Typhoon AUV at sea.

THESAURUS[1] project, during the FP7 European ARROWS[2] project, Allotta et al. (2015b) tests performed at the international workshop Breaking the Surface, held in Biograd Na Moru (Croatia) in October 2014 (Fig. 1) (Official Website of the International Workshop Breaking the Surface). Such experiments were performed to preliminary test the cooperative navigation between the two AUVs.

During the tests, the vehicle navigates in dead reckoning; the presented algorithm, along with the standard navigation filter of the Typhoon AUVs (which is based on the Extended Kalman Filter) are tested offline and their performance is compared, in order to evaluate the accuracy of the new navigation approach in estimating the vehicle dynamic behaviour. The obtained results are encouraging; in the near future, the proposed navigation filter will be implemented on the Typhoon AUVs and will be tested online in the water during experimental campaigns.

The paper is organised as follows: Section 2 introduces the Typhoon class AUV, briefly describing its structure and the sensors it is equipped with; Section 3 illustrates the mathematical models used to describe the vehicle behaviour, including its sensors and its propulsion system; in addition, a state-space representation of the vehicle model is derived. Section 4 illustrates the recursive navigation filters, both the standard and the proposed ones; the performance comparison among the two navigation algorithms and the experimental data are finally presented in Section 5.2.

2. AUV description

The Typhoon class AUV is a middle-sized class AUV developed and built by the Mechatronics and Dynamic Modelling Laboratory (MDM Lab) of the Department of Industrial Engineering of the University of Florence in the framework of the THESAURUS and the ARROWS projects.

The physical data of the vehicle are reported in Table 1, along with the achievable performance. Currently, two versions of the Typhoon AUV have been built, named respectively TifOne and

[1] THESAURUS project: www.thesaurus.isti.cnr.it
[2] ARROWS project: www.arrowsproject.eu