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Full Length Article

Navigation, guidance and control of an overactuated marine surface vehicle☆,☆☆

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ABSTRACT

This article presents navigation, guidance and control (NGC) experimental results obtained on an innovative overactuated unmanned surface marine vessel (USV) capable of omnidirectional motion. The results were obtained during sea trials in real environmental conditions where external disturbances and sensor characteristics have significant influence on the vehicle behavior. While performing the NGC experiments, the following set of behaviors is demonstrated: (1) successful heading control even in cases when the USV is performing simultaneous omnidirectional motion; (2) dynamic positioning algorithm performance with the navigation filter that uses only GPS measurement and a simple uncoupled dynamic model of an overactuated USV; (3) two line following algorithms (one using full actuation capabilities, and the other emulating underactuated line following) and comparing them by using quality metrics; and (4) online modification of mission parameters within the mission control architecture that is based on three layers (primitives, high-level and low-level control). Finally, we use results from multiple days of experiments to show how GPS update frequency influences (i) the quality of DP performance and (ii) the quality of the commanded control signal.

1. Introduction

The research area of marine robotics is becoming more popular as the need to understand the marine environment (underwater and surface) increases both for scientific and economic reasons. There is a substantial number of research groups all over the world who contribute to marine robotics research by developing their own underwater and surface autonomous marine platforms to be used for testing envisioned scenarios and algorithms. Unmanned marine surface vessels (USVs) are mostly being developed for science (e.g. exploration and observation, environmental data gathering and sampling, Caccia et al., 2007), bathymetric mapping (e.g. Manley, 1997), defense (e.g. mine-countermeasures Djapic and Nad (2010)), and general robotics research. A thorough list of unmanned surface marine vehicles until 2008 is given in Manley (September 2008) and Caccia, Bibuli, Bono, and Bruzzone (2008). In latter, the distinction is also made between vehicles for civil and military applications. Regardless of the fact that since then a large number of new unmanned vessels have been developed, they all have one thing in common: a classical hull shape (single hull or catamaran shaped vessels) that exploits favourable hydrodynamic properties to obtain long range operation with low energy consumption. Even though most of USVs are underactuated, i.e. use main propeller(s) and rudder(s) to perform basic manoeuvres such as heading and course keeping, point-to-point navigation etc., they can easily be equipped with additional bow thruster to achieve omnidirectional motion required for e.g. dynamic positioning. Another option for dynamic positioning is to use azimuth thrusters that enable vectored omnidirectional control (Sørensen, 2011). However, due to the shape of the hull, these vehicles are very inefficient in lateral motion.

On the other hand, marine vehicles that are designed for station keeping, such as large scale ocean platforms, are usually overactuated which allows them to hold position while keeping desired orientation. Due to their large scale, and complex deployment logistics, such platforms are not used for science purposes, but mostly for economically viable ocean exploitation.

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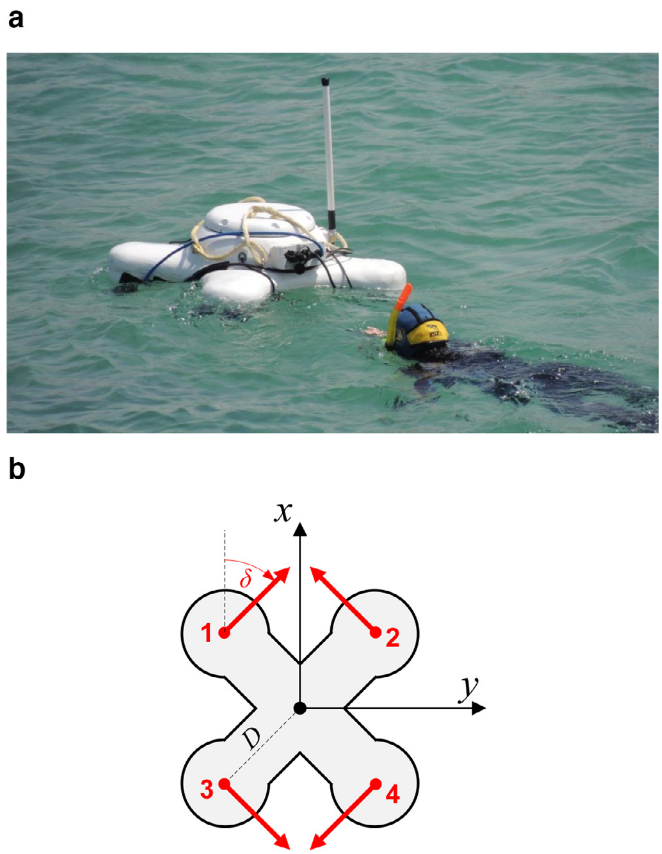

Fig. 1. (a) Prototype of the omnidirectional unmanned surface vessel *PlaDyPos* developed in LABUST (with a diver snorkeling for scale) and (b) "X" shaped actuator configuration that allows omnidirectional motion in the horizontal plane.

1.1. PlaDyPos – *an innovative unmanned omnidirectional surface marine vessel*

This article introduces a novel type of vessel, a small scale overactuated unmanned surface marine vehicle capable of omnidirectional motion, developed at the Laboratory for Underwater Systems and Technologies (LABUST) at the University of Zagreb, Croatia. The vessel, conveniently named *PlaDyPos* due to its initial purpose as a platform for dynamic positioning, we often refer to as the "platform", rather than just a USV. It is equipped with four thrusters in "X" configuration as shown in Fig. 1(b). This configuration enables motion in the horizontal plane under any orientation. The current version of the platform, shown in Fig. 1(a), is 0.35 m high, 0.707 m wide and long, and weighs approximately 25kg. Such vessel configuration is very convenient for research purposes due to easy deployment procedure, robustness in real environmental conditions, and low power consumption. Omnidirectional motion makes it very agile and thus applicable in tracking underwater agents capable of quick change of direction such as human divers – in the scope of FP7 project "CADDY – Cognitive Autonomous Diving Buddy"[1] it is used as a diver tracking platform that enables diver navigation and monitoring from the surface (Miskovic, Nad, & Rendulic, 2015). *PlaDyPos* is also used as a communication router between underwater and aerial vehicles in the scope of the DG ECHO project "Autonomous underwater vehicles ready for oil spill."[2] Further on, low power consumption allows a fleet of such vehicles to be used for long-term monitoring of underwater environment within the H2020 FET project "subCULTron – Submarine cultures perform long-term robotic exploration of unconventional environmental niches."[3] Omnidirectional motion allows *PlaDyPos* precise navigation and fast convergence to desired position/path which is crucial in applications such as mapping (obtaining mosaics and bathymetry) of shallow-water areas (Vasilijevic et al., 2015), and mine countermeasures (Miskovic et al., 2014), where the platform is used to remotely dispose of freely floating unexploded ordnance.

Research that involves the use of *PlaDyPos* USV has been divided into three phases: (1) simulations, (2) navigation, guidance and control (NGC) experiments, and (3) application scenarios. The simulation phase involves a number of simulation experiments where elementary navigation, guidance and control algorithms were tested under realistic simulation conditions. Additionally, application scenarios were included in these simulations where special attention was devoted to ensuring realistic modeling of the sensors used in the platform. The simulation phase results have been reported and analyzed in Miskovic, Nad, Stilinovic, and Vukic (2013) where the proof of concept for diver tracking algorithms has been demonstrated. The NGC experiments phase includes experimental verification of algorithms performed in real life conditions, where external disturbances and sensor characteristics have significant influence on the vehicle behavior. The application scenarios phase includes experimental verification of the envisioned scenarios such as diver tracking, mosaicing, bathymetry, etc. The experimental results for both the second and the third phase have been obtained in 2013 and 2014 during field trials in Croatian Navy base Split and Murter, Croatia.

1.2. *Contributions and organization of the article*

This article reports the results and validates the quality of the navigation, guidance and control experiments, which are the basis for successful completion of different application scenarios. Firstly, we focus on experimental NGC results obtained on the omnidirectional unmanned surface vessel demonstrating the quality of the following set of behaviors:

1. Successful heading control even in cases when the platform is performing simultaneous omnidirectional motion;
2. dynamic positioning algorithm performance with the navigation filter that uses only GPS measurement and a simple uncoupled dynamic model of an overactuated USV;
3. two line following algorithms: (a) using full actuation capabilities, i.e. vectored control, and (b) emulating underactuated line following characteristic for rudder-based vessels;
4. online modification of mission parameters within the mission control architecture that is based on three layers (primitives, high-level and low-level control).

Secondly, we compare the two implemented line following algorithms by using quality metrics based on mean distance to the desired line obtained on real life experiments.

Finally, we show how GPS update frequency influences (i) the quality of DP performance and (ii) the quality of the commanded control signal.

The article is organized as follows. Section 2 presents the mathematical model of the overactuated USV, and the models of observed navigation, guidance and control behaviors such as dynamic positioning and line following. Section 3 describes the implemented control structure consisting of filtering and estimation, low-level (speed) controllers, high-level controllers (heading, dynamic positioning, line following), primitives and mission control. Section 4 presents experimental results obtained in a real-life environment, together with a comparison of the two implemented line-following algorithms. Section 5 focuses on the analysis of influence of GPS quality to the behavior of the navigation filter relative to the experimental results. The article is concluded with Section 6.

[1] http://caddy-fp7.eu/
[2] http://www.upct.es/urready4os/
[3] http://subcultron.eu/

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