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Cooperative line of sight target tracking for heterogeneous unmanned marine vehicle teams: From theory to practice

Thomas Glotzbach [a,*], Matthias Schneider [b], Peter Otto [b]

[a] *Laboratory of Robotics and Systems in Engineering and Science (LARSyS), Instituto Superior Técnico (IST), University of Lisbon, Torre Norte - 8, Av. Rovisco Pais, 1, 1049-001 Lisboa, Portugal*

[b] *Institute for Automation and Systems Engineering, Ilmenau University of Technology, P.O. Box 100565, 98684 Ilmenau, Germany*

HIGHLIGHTS

- We describe an algorithm for target tracking by a team of autonomous marine vehicles.
- A general control architecture for such a team is described.
- Focus is put on tracking an underwater target by a team of autonomous marine vehicles.
- The tracking algorithm was validated in real sea trials.
- In the trials, an acoustic communication link was in the loop.

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ABSTRACT

In this paper we present the principle of Cooperative Line Of Sight Target Tracking (CLOSTT) for Heterogeneous Unmanned Marine Vehicle Teams. Thereby CLOSTT is part of a control architecture developed to coordinate existing single heterogeneous autonomous marine vehicles as a team. Within this control architecture CLOSTT separately offers a solution to the task of following a moving underwater target with a team of unmanned marine vehicles.

1. Introduction

The cumulative industrialization and exploitation of the ocean leads to an increasing demand of autonomous underwater vehicles (AUVs). The challenges posed by the realization of teams of AUVs were addressed in the European research project GREX.[1] The research work in GREX aimed to create a conceptual framework and middleware systems to coordinate a swarm of diverse, heterogeneous unmanned marine vehicles working in cooperation to achieve a well defined practical goal in an optimized manner. The development of CLOSTT was inspired by a scenario from the area of marine biology which focused on the task to find and follow a fish previously tagged with an electronic device that collects data about the fish behavior. CLOSTT takes into account the constraints caused by the marine mission environment and the employment of heterogeneous vehicles. This circumstances demand a principle that allows the usage of different control concepts for single autonomous marine vehicles, where the coordination level needs to be placed on top with little and well defined interactions into the existing controls. Furthermore, the employment of unmanned marine vehicle teams in close range towards each other requires new safety mechanisms which do so far not exist for single autonomous vehicles. Finally, the acoustic communication with its very low bandwidth and poor reliability is a serious bottleneck for the control concept. The task to follow a target whose position information will be available only one or two times per minute excludes the usage of classical follower concepts approved in land and air robotics, which can be found in literature.

An overview can be found in [1], and the references therein. Bibuli et al. present a concept where an unmanned surface vehicle follows a leading vehicle, trying to execute the previous unknown path used by the leader. This is an adequate approach for a movement through an area with obstacles, were the follower is

* Corresponding author.
E-mail addresses: thomas.glotzbach@tu-ilmenau.de (T. Glotzbach), schneider.matthias@tu-ilmenau.de (M. Schneider), peter.otto@tu-ilmenau.de (P. Otto).

[1] GREX (2006–2009) was performed by: ATLAS ELEKTRONIK GmbH (Germany), University of the Azores (Portugal), Ifremer (France), Innova S.p.A. (Italy), Instituto Superior Técnico (IST) (Portugal), MC Marketing Consulting (Germany) SeeByte Ltd. (Great Britain), and Ilmenau University of Technology (Germany).

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0921-8890/

expected to stay as close to the path of the leader as possible, to prevent collisions. Other interesting results can be found in [2], where several unmanned surface crafts followed a manned vehicle that was allowed to move randomly, keeping a close formation, like it is reasonable if the vehicles are intended to perform a common survey. In [3], a scenario is used in which two surface vehicles linked by a rope are intended to capture and to transport a floating target. All these applications differ considerably from the scenario that inspired our work. As we will discuss in Section 2, we intend to follow a submerged target in an area without obstacles, and the target positions can only be estimated based on acoustic communication; therefore, trying to follow the exact path used by the target is neither reasonable nor possible. Additionally to the examples from literature, our approach must be robust enough to allow for an AUV in the group of followers, resulting in another acoustic link with its limited bandwidth and poor reliability.

We will show the complete development process of the CLOSTT-proceeding, from theory to practice. In Section 2, we will describe the concrete mission scenario that inspired us to the development of CLOSTT. Furthermore, we will give a conceptual description of the functionality of the GREX concept and how it enables existing single autonomous vehicles to cooperate with each other. Section 2 will be closed by the description of formation keeping for autonomous vehicles on preplanned paths, which we realized in the GREX software, based on research results of our project partners. With all the preconditions explained and focusing on our contribution, in Section 3 we will present the geographical description of the CLOSTT path planning and the realization in software. Section 4 shows the verification in simulation and proves the practicability by describing the successful usage of the CLOSTT concept during the final GREX sea trials, where a realistic mission scenario could be performed which included an acoustic communication link within the control loop.

2. The GREX project

2.1. Mission scenario

The principle of CLOSTT was developed to offer a solution to a mission scenario formulated by marine biologists. They aim to broaden their knowledge on the behavior of different marine species, like fishes, by exploring their living habitats, routes typically used, places visited, and so on. For that reason, they put electronic devices on caught living fishes which will collect the desired data after the release of the fish. The big challenge is the retrieval of this data. A possible solution exists in following the fish with a team of autonomous marine vehicles (mainly surface crafts) in order to guide an AUV close enough to the fish to start the download of the data via acoustic communication. As the acoustic communication, by means of exchanging pings, measures the runtime to employ trilateration algorithms to determine the exact position of the fish, a group of at least three vehicles is necessary to perform the mission. The principle is shown in Fig. 1.

The procedure to solve this challenge must consider the poor communication abilities between both the target and the followers as well as between the team members itself. The amount of information of the target will be limited, and coordination activities within the team must pass through the acoustic communication bottleneck.

2.2. Cooperative behavior for heterogeneous vehicles

Within the GREX project, the aim was to realize cooperative teams of Multiple Unmanned Marine Vehicles. As a precondition for a possible market launch, no new vehicles were developed, but the solution was designed to be able to run on a large number of existing ones. This demanded heterogeneity limited the possibilities for control algorithms in several aspects. Many vehicle providers are not willing to give detailed information about the existing control software, running on their single autonomous vehicles. On the other hand, they will also not allow to completely replace their existing software, as it usually contains several safety concepts that need to remain active, especially during team missions. A special challenge of the GREX project was the development of a middleware system that would be able to run on top of the existing control hard- and software systems, exchanging data and commands only by a defined interface module which would make it possible for the vehicle providers to perform validations on the side of the existing control concept and to deny every command which is classified to be improper.

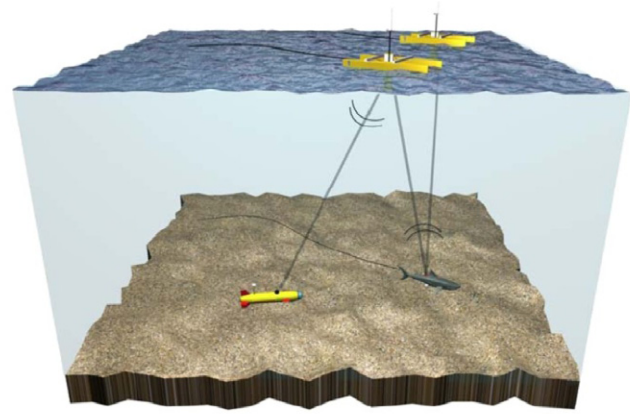

Fig. 1. The Fish Data Download scenario.

To enable the setup of the GREX middleware system, a Team-Oriented Mission Planning (TOMP) [4] was necessary as a base to start from. Thereby the user is able to create a mission plan for a whole team in a simplified way. This team plan is split by the planning tool into single vehicle mission plans which are then further translated into the real vehicle mission plans, formulated in their individual languages. During mission execution each vehicle executes its own mission plan. The team instance of the GREX software runs in parallel through the original team mission plan and is able to send replanning commands to the existing vehicle control software. That way, it is guaranteed that the existing control architecture of each single vehicle stays in power, although a team instance exists that is responsible for a cooperative behavior between the vehicles. Therefore the GREX dedicated software for cooperation runs on a separated hardware (the GREX black box) inside each vehicle and exchanges data via a defined interface module. Only through the collaboration of the several and specialized modules a team oriented behavior can be realized.

The GREX dedicated software consists of four modules. The Communication Module is responsible for the complete communication between several vehicles via radio, Wi-Fi or acoustics as well as for the vehicles internal communication between the GREX modules [5]. Team Navigation estimates the position of all team mates based on a complex estimator structure using acoustic range measurements, the spare position information of the other vehicles, and the current track data, like described as concept in [6]. Both modules were developed by project partners. Due to the use of different existing single autonomous vehicles within the GREX research project an Interface Module is necessary which provides a communication link between the existing vehicle hardware and the GREX components (modules were developed by each vehicle provider in the project). We created the Team Handler Module which realizes the complete management of a team and enables the team oriented behavior of a single autonomous vehicle by observing position data, evaluating the GREX team mission plan and