Underwater communication with artificial electric sense

Mohamed Boukens\textsuperscript{1}, Vincent Lebastard\textsuperscript{1}, Godfried Jansen Van Vuuren\textsuperscript{2}, Frédéric Boyer\textsuperscript{1}

\textsuperscript{1}Institut Mines Telecom Atlantique, Laboratoire des Sciences du Numrique de Nantes
\textsuperscript{2}Scuola Superiore Sant’Anna, The Biorobotics Institute, Pontedera, Italy
frederic.boyer@imt-atlantique.fr

Abstract

Underwater communication is a challenging issue for underwater robotics. This is especially the case for swarm robotics in confined spaces and turbid waters where neither sonar nor light can be used. This paper presents a new perspective for addressing this issue. The approach is based on artificial electric sense, a sensing ability inspired from weakly electric fish that can perceive their surroundings and communicate within a group by interpreting the electric fields generated by themselves or by conspecifics. This concept is implemented on a heterogeneous swarm of underwater robots, named subCULTon, which is able to cooperate in order to explore and monitor its environment in the harsh conditions of the Venice Lagna.

Introduction

Due to some intrinsic physical limitations, underwater communication in confined spaces and turbid water still remains a challenging issue for underwater robotics (Lanzagorta (2012); Gussen et al. (2016)). To address it, a promising perspective consists in taking inspiration from the several hundred of fresh water fish species that have evolved an original sense, named active electric sense. Discovered by Lissman and Machin in the 50s (Lissmann and Machin (1958)), electric sense allows these fish to navigate, detect prey and predators, and communicate together, in the turbid waters, saturated with obstacles, of the African and south-American rain forests (von der Emde and Schwarz (2002); Pereira et al. (2012), Gebhardt et al. (2012)). Suited to underwater navigation in confined space and turbid waters, this artificial electric sense has been applied to several issues in underwater robotics ranging from reactive navigation (Boyer et al. (2013, 2015)), object localization (Silverman et al. (2012); Lebastard et al. (2010)) and recognition (Bai et al. (2012); Lanneau et al. (2017)), to haptic feedback remote control (Fang et al. (2016); Boyer et al. (2019)).

Objectives and challenges

In this paper, we will show how artificial electric sense can be used for communication in a swarm of small underwater robots. This new functionality of artificial electric sense is implemented and tested on a heterogeneous swarm named subCULTon (Thenius (2018)). This swarm, which is designed to monitor the turbid waters of the Venice laguna, is composed of three types of robots named aPads, aFish and aMussels (Lončar et al. (2019)). The aPads are surface platforms that integrate the underwater data collected by the aFish and aMussels. The aMussels (see figure 1(a)) are essentially static robots that monitor their surroundings on the sea bottom thanks to several sensors (temperature, turbidity, oxygen...), while aFish are small mobile AUVs (See figure 1(b)) able to navigate encumbered spaces while serving as the vector of information for the swarm. As a proof of concept, we here address the following scenario. An aFish is used as a messenger that propagates information through 2 aMussels. To achieve this goal, the aFish needs to be endowed with several behaviors (taxis) as: "exploring an unknown environment while avoiding obstacles", "detecting an aMussel and aggregate with it", "retrieve the message of the aMussel, disaggregate with the aMussel", and repeat the same strategy until it finds another aMussel to which the message is delivered to. This scenario raises the following issues. I1: Organize the electric activity of our robots in group in order to preserve information for communication. I2: Ensure aFish to navigate while avoiding obstacles (including other aFish or inactive aMussels) and to aggregate with active aMussels. I3: All these functionalities have to work independently of water conductivity.

Figure 1: aMussels (a) and aFish (b) designed by Scuola Superiore Sant’Anna (SSSA).
Methods

To use electric sense for communication in a swarm of robots (I1), we take inspiration from the original fish which can be roughly classified in two types depending whether they emit an harmonic electric field with a controlled frequency or a train of pulses. The first are named wave-fish (Pereira et al. (2012)), the second, pulse-fish (von der Emde and Schwarz (2002)). Remarkably, these two types of fish have evolved some specific emission-reception strategies allowing them to avoid jamming between their fields, and so to preserve the informational content for communication (Bullock et al. (1972); Schumacher and von der Emde (2012)).

In the case of wave fish, they slightly change their emission frequency between them according to some hierarchical position in the group (Bullock et al. (1972)).

The electric activity of a variable structure controller (right). C

Figure 2: Graph of events of the desynchronisation algorithm of aMussels and aFish (left), and of the variable structure controller of aFish navigation (right). C

In the case of pulse fish, they desynchronize their electric activity in order to emit their pulse one after the other in a fixed ordered manner (Schumacher and von der Emde (2012)). In this paper, we will see how one can mix these two strategies to organize the electric activity of the robots of the subCLUTron swarm. In more detail, the fields are harmonic but emitted over time windows which are opened and closed according to a desynchronization algorithm inspired from those proposed to explain the synchronization of blinking in fireflies (Tyrrell et al. (2006)). While the aPads are not considered in the article, the desynchronization algorithm is implemented on aMussels and aFish in order to manage their electric activity in interaction with other robots (see figure 2(left)). In the case of aFish, this algorithm also manage the electric activity of a variable structure controller based on fuzzy logic (see figure 2 (right)), which allows them to seek for aMussel as well as to aggregate and communicate with them (I2). To achieve these several capabilities together, we need to hybridize active (P) and passive (P) electric sense, the first being useful for exploration and obstacle avoidance, the second for aggregation (A) and communication. Moreover, the informational content of an electric field is separated into its amplitude and frequency, where both need to be measured independently with new hardware. Finally, to address I3, the new sensor hardware which uses a frequency-shift keying (FSK) protocol for decoding messages (Kennedy and Davis (1985)), has been evolved in order to ensure the expected specifications of the swarm in fresh and salt waters.

Results

Experimental tests with both aMussels and aFish were carried out in a cubic tank of 2m width, filled with salt water that has a conductivity of得住 $\gamma \approx 3.5 \text{ S/m}$. We report in figure 3 one result that illustrates obstacle avoidance of one aFish, two passive aMussels (black circles), and two walls (black segments). The desynchronization algorithm and the fuzzy variable structure controller of figure 2 are used with parameters fixed once for all by trial and error in a preliminary calibration phase.

Figure 3: Paths of the aFish navigating with the controller of figure 2 in obstacle avoidance behavior C1 (blue) and C2 (green).

Acknowledgements

This research was funded by European Union Horizon 2020 research and innovation program under grant agreement No 640967: EU-FET proactive project subCLUTron (SUBmarine Cultures perform Long-Term Robotic Exploration of unconventional environmental Niches) https://cordis.europa.eu/project/id/640967/fr.
References


