Underwater communication with artificial electric sense

Mohamed Boukens, Vincent Lebastard, Godfried Jansen van Vuuren, Frédéric Boyer

Underwater communication with artificial electric sense

Mohamed Boukens[1], Vincent Lebastard[1], Godfried Jansen Van Vuuren[2], Frédéric Boyer[1]

[1]Institut Mines Telecom Atlantique, Laboratoire des Sciences du Numrique de Nantes
[2]Scuola Superiore Sant'Anna, The Biorobotics Institute, Pontedera, Italy
frederic.boyer@imt-atlantique.fr

Abstract

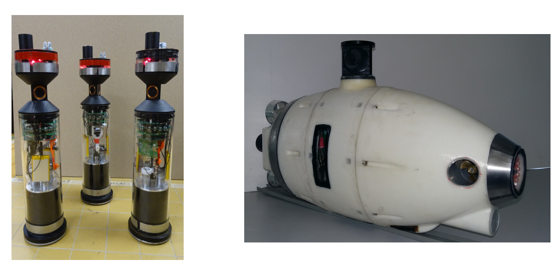
Underwater communication is a challenging issue for underwater robotics. This is especially the case for swarm robotics in confined spaces and turbid waters where neither sonar nor light can be used. This paper presents a new perspective for addressing this issue. The approach is based on artificial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

Introduction

Due to some intrinsic physical limitations, robotics underwater communication in confined spaces and turbid water still remains a challenging issue (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 Lisman and Machin in the 50s (Lissmann and Machin (1958)), electric sense allows these fish to navigate, detect preys and predators, and communicate together, in the turbid waters, saturated of 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 an 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 closed surrounding 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 to find another aMussel to which the message is delivered. 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.



(a) (b)

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)).

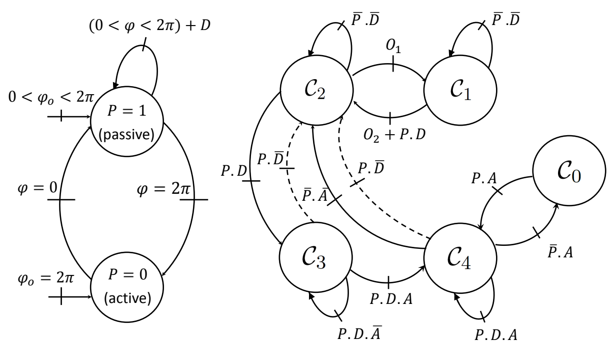


Figure 2: Graph of events of the desynchronisation algorithm of aMussels and aFish (left), and of the variable structure controller of aFish navigation (right). $C_{0,1,2,3,4}$ defines 5 reactive controllers for communication ($C_{3,4}$), obstacle avoidance ($C_{1,2}$), aggregation ($C_{3,4}$). Transitions between continuous controllers are governed by the time evolution of Boolean variables depending on the electric measurements: D means that an exogenous field is detected, P means "passive", and A "aggregated".

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 subCULtron swarm. In more details, the fields are harmonic but emitted over some 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 ($\bar{P}$) 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, that both need to be measured independently with a 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, full of salt water with conductivity $\gamma \cong 3.5$ S/m respectively. We report in figure 3 one result that illustrates obstacle avoidance of one aFish with two passive aMussels (circles), and two walls. 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.

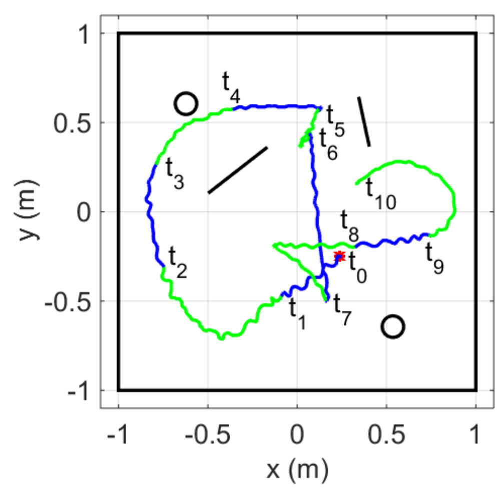


Figure 3: Paths of the aFish navigating with the controller of figure 2 in obstacle avoidance behavior $\mathcal{C}_1$ (blue) and $\mathcal{C}_2$ (green).

Acknowledgements

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

References

Bai, Y., Snyder, J., Silverman, Y., Peshkin, M., and MacIver, M. (2012). Sensing capacitance of underwater objects in bio-inspired electrosense. In *2012 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pages 1467–1472.

Boyer, F., Lebastard, Ferrer, S., and Geffard, F. (2019). Underwater pre-touch based on artificial electric sense. *International Journal of Robotics Research (IJRR)*, 39(6):729–752.

Boyer, F., Lebastard, V., Chevallereau, C., Mintchev, S., and Stefanini, C. (2015). Underwater navigation based on passive electric sense: New perspectives for underwater docking. *The International Journal of Robotics Research*, page 0278364915572071.

Boyer, F., Lebastard, V., Chevallereau, C., and Servagent, N. (2013). Underwater reflex navigation in confined environment based on electric sense. *IEEE Transactions on Robotics*, 29(4):945–956.

Bullock, T., Hamstra, R., and Scheich, H. (1972). The jamming avoidance response of highfrequency electric fish, part i & ii. *J Comp Physiol*, 77:1–48.

Fang, S., Peshkin, M., and MacIver, M. (2016). Human-in-the-loop active electrosense. *Bioinspiration & Biomimetics*, 12:014001.

Gebhardt, K., Böhme, M., and von der Emde, G. (2012). Electrocommununication in social groups of weakly electric fish: a comparison of mormyrus rume and marcusenius altisambesi (mormyridae, teleostei). *Frontiers in Behavioral Neuroscience*, (00235).

Gussen, C. M., Diniz, P. S., Campos, M. L., Martins, W. A., Costa, F. M., and Gois, J. N. (2016). A survey of underwater wireless communication technologies. *J. Commun. Inf. Sys.*, 31(1):242–255.

Kennedy, G. and Davis, B. (1985). *Electronic communication systems*, volume 20. Tata McGraw-Hill Publishing Co. Ltd., New Delhi.

Lanneau, S., Boyer, F., Lebastard, V., and Bazeille, S. (2017). Model based estimation of ellipsoidal object using artificial electric sense. *The International Journal of Robotics Research*, 36(9):1022–1041.

Lanzagorta, M. (2012). Underwater communications. *Synthesis Lectures on Communications*, 5(2):1–129.

Lebastard, V., Chevallereau, C., Amrouche, A., Jawad, B., Girin, A., Boyer, F., and Gossiaux, P. B. (2010). Underwater robot navigation around a sphere using electrolocation sense and kalman filter. In *IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*.

Lissmann, H. and Machin, K. (1958). The mechanism of object location in gymnarchus niloticus and similar fish. *Journal of Experimental Biology*, 35(2):451–486.

Lončar, I., Babić, A., Arbanas, B., Vasiljević, G., Petrović, T., Bogdan, S., and Mišković, N. (2019). A heterogeneous robotic swarm for long-term monitoring of marine environments. *Applied Sciences*, 9(7):1388.

Pereira, A., Aguilera, P., and Caputi, A. (2012). The active electrosensory range of gymnotus omarorum. *The Journal of Experimental Biology 215,*, 215:3266–3280.

Schumacher, S. and von der Emde, G. (2012). Jamming avoidance during active electrolocation of objects in the weakly electric fish, gnathonemus petersii. *Frontiers in Behavioral Neuroscience*, (00230).

Silverman, Y., Snyder, J., Bai, Y., and MacIver, M. (2012). Location and orientation estimation with an electrosense robot. In *Workshop on IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS),*, pages 4218–4223.

Thenius, R. e. a. (2018). subcultron - cultural development as a tool in underwater robotics. In *Artificial Life and Intelligent Agents*, pages 27–41, Cham. Springer International Publishing.

Tyrrell, A., Auer, G., and Bettstetter, C. (2006). Synchronization inspired from nature for wireless meshed networks. In *Wireless Communications, Networking and Mobile Computing, 2006. WiCOM 2006. International Conference on*, pages 1–4. IEEE.

von der Emde, G. and Schwarz, S. (2002). Imaging of objects through active electrolocation in gnathonemus petersii. *Journal of Physiology-Paris*, 96(5:6):431 – 444.