Artificial repulsive pheromone approach for the exploration of ocean dynamics

Fabrice Le Bars[1], Luc Jaulin[1], Olivier Ménage[1,2], Aurélien Ponte[2]

[1]Lab-STICC, ENSTA-Bretagne, 2 rue François Verny, 29200 Brest - France
[2]Ifremer, Universite de Brest, CNRS, IRD, Laboratoire d'Oceanographie Physique et Spatiale (LOPS), IUEM, Brest, France

fabrice.lebars@ensta-bretagne.fr, lucjaulin@gmail.com, olivier.menage@ifremer.fr, aurelien.ponte@ifremer.fr

Abstract

In this paper, we propose a swarm robotic approach to construct a time-dependent map of an ocean water mass properties (*e.g.,* hydrological properties such as temperature and salinity, currents) for a chosen time period. For this purpose, we seed and track the water mass with several drifting buoys. Then, we propose to accompany the buoys by a swarm of autonomous boats collecting measurements around buoys. To avoid collecting data at places that have already been visited few minutes before (which would be of little interest), we ask our robots to release some artificial repulsive pheromones.

Keywords. Robotics, Exploration, Artificial pheromones, Bio-inspired, Swarm robotics, Ocean currents

1 Introduction

A long standing oceanographic challenge deals with the in situ measurement of the evolution of water masses near the ocean surface as they are transported by ocean currents, mix with surrounding water masses, and, exchange heat and moisture with the atmosphere [1] [2]. These observations are required in order to model and forecast the state of the ocean and, more generally, of the Earth system over climatic timescales. Past approaches involved drifting buoys and environmental measurements were limited to buoy locations and failed to provide a description of the surrounding which is required in order to explain the evolution of the tracked water mass.

The use of autonomous surface vehicles is foreseen as an up and coming revolution for oceanographic in situ observations and there is a dire need for tailored algorithmic development. In this paper, we propose as a result to accompany the buoys by several autonomous boats scanning zones near the buoys. Now, due to the fact that the buoys moves and diverge in a manner that may be difficult if not impossible to predict, a deterministic and thorough scan is not possible. Instead, we propose to use autonomous boats which behave as a swarm, without any leader, exchanging information relate to their positions in order to reconstruct individually a pheromone map describing the part of the ocean that have been visited few minutes before.

The approach we propose is bio-inspired. Indeed, in biology, pheromones are chemical substances released into the environment by an individual social insects. Pheromone communication has been adopted to swarm robotics domain using diverse approaches [3][4]. In robotics, the pheromones have no real existence and are artificial, *i.e.*, there exist in the memory of the computers of each robot forming the swarm. The evaporation process is emulated by each individual. For exploration purpose, pheromones are used in a repulsive manner in order to collect data as scattered as possible in the time-space. The offline interpolation will then allow us to have a reliable interpretation of the ocean motion.

2 Swarm

Swarm robotics studies of how a large number of simple rules for individual robots translates into a collective behavior. Usually the global behavior is reached by local interactions among the robots and the environment. One of the first example is given in [5] where attractive pheromones are used so that ants-like robots follow the same path. In our context, since we want to explore at different places, repulsive pheromones will be preferred. Moreover, contrary to Reynolds rules [8] which only takes into account the current state, pheromones allow us to represent the knowledge of which parts of the environment have been explored recently.

Pheromones can be seen as a primitive communication system, easy to implement in the context of swarm robotics. For this, it suffices to leave some marks in the environment [9]. Now, this is not realistic in our ocean exploration where we want to avoid any pollution of the ocean. Instead, we prefer to use an existing communication system where each individual broadcast their own positions so that each robot it able to reconstruct artificially the pheromone map.

3 Formalism

We consider n robots $\mathcal{R}_i, i \in \{1, \ldots, n\}$ described by the state equations

$$\mathcal{R}_i : \begin{cases} \dot{x}_i &= \cos \psi_i \\ \dot{y}_i &= \sin \psi_i \\ \dot{\psi}_i &= u_i \end{cases} \tag{1}$$

where (x_i, y_i) is the position of $\mathcal{R}_i$ and ψ_i it its heading. This model known as Dubins car [6] is perfectly suited to illustrate simply the motion of a boat.

Define by $\phi(\alpha, \beta, t)$ the pheromone function which depends on the space position (α, β) and time t. When ϕ is high, it means that we do need to go at position (α, β) at time t because of two reasons:

- An obstacle (possibly moving) exists and we want to avoid the collision
- or we are at time t and the position (x, y) has been visited recently by some other robots

Moreover, the pheromone function has an evolution which is influenced by two factors: the evaporation and the visit:

$$\frac{\partial \phi}{\partial t}(\alpha, \beta) = \underbrace{-p_1 \phi(\alpha, \beta)}_{\text{evaporation}} + \underbrace{\sum_i e^{-\frac{(\alpha-(x_i-\cos\psi_i))^2+(\beta-(y_i-\sin\psi_i))^2}{p_2}}}_{\text{visit}} \tag{2}$$

This is illustrated by Figure 1 where the three robots (green) sow pheromones (black) behind them. The pheromones tend to disappear with time. Two buoys are represented in red. The persistence parameter p_1 is small ($\simeq 0.001$) if we judge that there is no need to explore an area that has been visited recently. The granularity parameter p_2 is large if we believe that it is unnecessary to visit a zone near in space to another robot. In practice, the function $\phi(\alpha, \beta)$ is represented by a black and white image with different levels of gray. This image is stored in a memory which is shared between all robots.

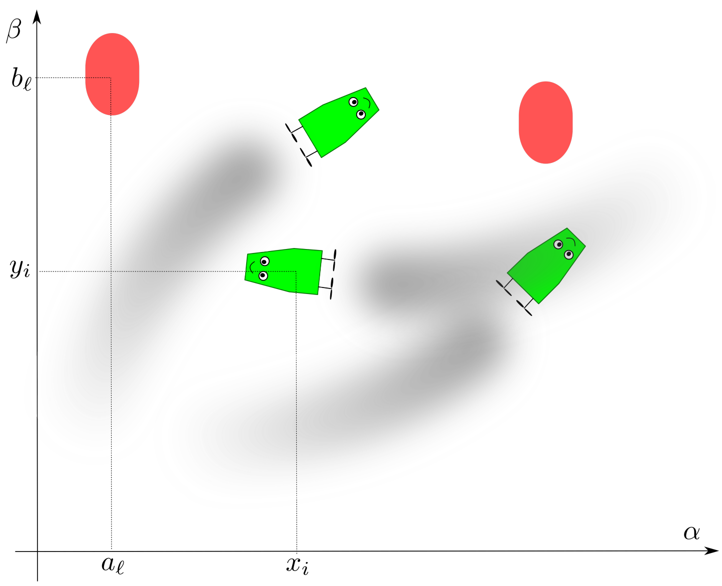

Figure 1: Each robot sows behind it some repulsive artificial pheromones

We create the artificial force (corresponding to the heading that has to follow the robot) [7] for the ith robot:

$$\mathbf{f}_i = \underbrace{-\text{grad}\phi}_{\text{repulsive pheromones}} - \underbrace{p_3 \cdot \sum_{j \neq i} \frac{\mathbf{r}_{ij}}{\|\mathbf{r}_{ij}\|^3}}_{\text{repulsion between robots}} + \underbrace{p_4 \cdot \sum_{\ell} \begin{pmatrix} a_\ell - x_i \\ b_\ell - y_i \end{pmatrix}}_{\text{attraction by the buoys}} \tag{3}$$

where

$$\mathbf{r}_{ij} = \begin{pmatrix} x_j - x_i \\ y_j - y_i \end{pmatrix} \tag{4}$$

and (a_ℓ, b_ℓ) correspond to the position of the ℓ'th buoy.

For the control, we take the classical proportional controller

$$u_i = p_5 \cdot \text{sawtooth}(\text{atan2}(\mathbf{f}_i) - \psi_i) \tag{5}$$

The parameters have to be tuned in order to have an acceptable behavior of the swarm. For our simulation, we have taken $p_1 = 0.001$ (evaporation), $p_2 = 10$ (granularity), $p_3 = 50$ (repulsion), $\text{p}_4 = 0.1$ (buoys attraction) and $p_5 = 0.2$ (rotation rate).

4 Simulation

Figure 2 proposes a simulation which illustrates the behavior of the swarm.

(a) Initially, the buoys and the robot are set randomly in a specific zone of the ocean.

(b) Due to the short range repulsion, the robot first escape from the initial zone

(c) The robots move in a zone around the buoys. In the green circle, we see a robot turning right, influenced by the repulsive pheromones, to avoid the visit of a zone already explored few minutes before by another robot.

(d) Sometimes a robot makes a converging spiral due to the fact that it is repelled by its own pheromones, Now, due do its radius of curvature imposed by its state equations, this spiral has a limited effect.

(e)-(h) the buoys continue their erratic evolution and the swarm stays nearby.

A video with ten robots and 7 buoys is given at https://youtu.be/DdAGE8_uBv0

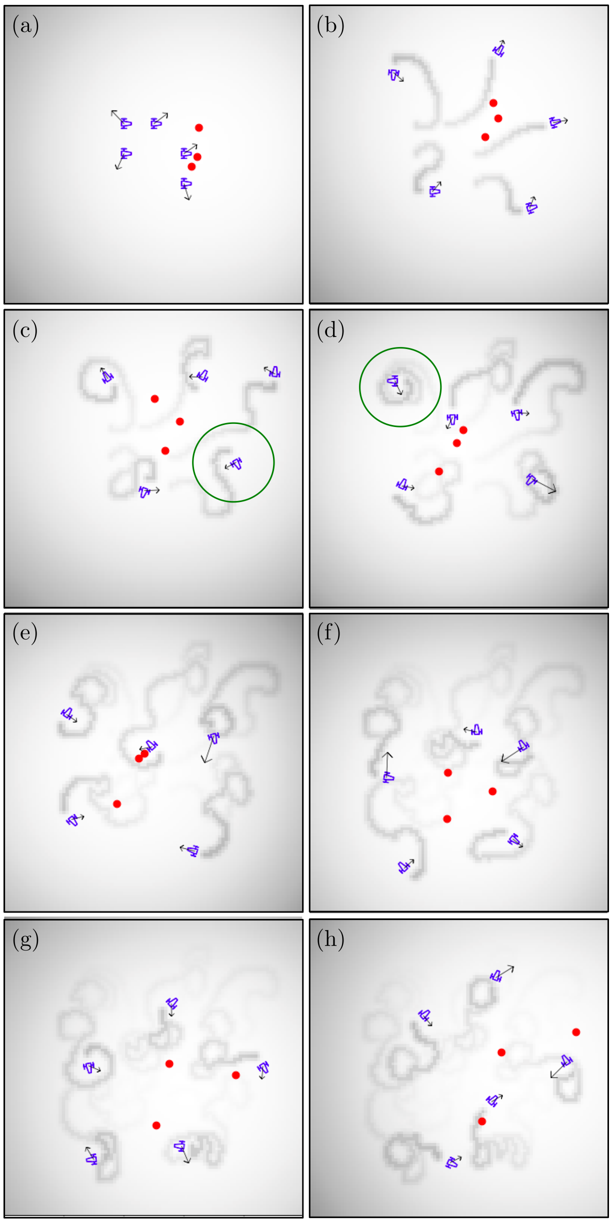

Figure 2: Simulation of the swarm piloted by repulsive artificial pheromones

5 Experiment

For the "*journées démonstrateur*" https://demonstrateur22.sciencesconf.org/ that takes place in Angers, june 2022, we have thrown 3 buoys which send their position via Iridium https://www.iridium.com/ at each time and publish them through a web site via the *Pacific Gyre* platform. The autonomous robot *mobesens* (Figure 3) collects data within a zone delimited by the drifting buoys.

Figure 3: The autonomous kayak *Mobesens* moves around the buoys to collect data, Mobesens : Angers, 2022, June 22

6 Conclusion

In this paper, we have presented a pheromone approach in order to monitor the evolution of a water mass along with its surroundings. We have chosen a Lagrangian approach where buoys are used as markers of a water mass and are transported along with the water mass by ocean currents. Autonomous boats move in order to collect relevant environmental data trying to cover and sample the water mass surroundings. To achieve this goal, a repulsive pheromone approach has been chosen in order to be robust with respect to unpredictable events (collision, meteorology, etc) and to limit the communication between robots. Some simulations and an experiment have shown the feasibility of the approach.

The Python source code associated to the simulation can be found in [11].

References

[1] E.A. D'Asaro, A.Y. Shcherbina, et. al. "*Ocean convergence and the dispersion of flotsam*". Proceedings of the National Academy of Sciences, 2018.

[2] A.Y. Shcherbina, M.A. Sundermeyer, et. al. *The LatMix Summer Campaign: "Submesoscale Stirring in the Upper Ocean*", Bulletin of the American Meteorological Society, 2015.

[3] Seongin Na et. al. , *"Bio-inspired artificial pheromone system for swarm robotics applications"*, Adaptive Behavior, n 29, pp. 395-415, 2020.

[4] F. Arvin, et al. "*Imitation of honeybee aggregation with collective behavior of swarm robots*" International Journal of Computational Intelligence Systems 4.4 (2011).

[5] A. Russell, "*Ant trails-an example for robots to follow?*" IEEE International Conference on. Vol. 4. IEEE, 1999.

[6] L. Dubins, "*On curves of minimal length with a constraint on average curvature, and with prescribed initial and terminal positions and tangents*", American Journal of Mathematics, 1957.

[7] O. Khatib, "*Real-time obstacle avoidance for manipulators and mobile robots*" International Journal of Robotics Research, 1986.

[8] C. Reynolds. "*Flocks, herds and schools: A distributed behavioral model*". SIGGRAPH'87: Proceedings of the 14th Annual Conference on Computer Graphics and Interactive Techniques. 1987.

[9] S. Toshiki, and D. Kurabayashi. "*Artificial pheromone system using rfid for navigation of autonomous robots*" Journal of Bionic Engineering, 2007

[10] L. Jaulin, *Mobile robotics*, Iste Wiley, 2015.

[11] L. Jaulin, *Python code for the simulations of the pheromone-based exploration* https://www.ensta-bretagne.fr/jaulin/pheromone.html