www.onera.fr

ONERA
THE FRENCH AEROSPACE LAB

POST-DOCTORATE PROPOSAL

Title: New particle filters for underwater Terrain-Aided Navigation.

Reference : **PDOC-DTIS-2023-01**
(to be recalled in all correspondence)

Start of contract: 01/01/2023	**Application deadline:** 31/12/2023

Duration: 12 months, possibly extendable to 24 months - Net yearly salary: about 25 k€ (medical insurance included)

Keywords: Particle filters, Terrain-Aided Navigation, Sensors fusion

Profile and skills required:

Applied mathematics with an emphasis on Probabilities/Statistics.

Presentation of the post-doctoral project, context and objective

Inertial navigation systems (INS) are often the main source of navigation data in autonomous underwater vehicles (AUV) since they are independant and reliable. However, it is well known that these components drift due to alignment error and the accumulation of sensor errors over time. This drift may be inconsistent with the navigation performance requirements. To correct the navigation drift, IMU can be combined with other external sensors. A common aiding source is the Global Positioning System (GPS) but resurfacing for GPS is often excluded for discretion requirements and also because it can be easily jammed.

Usually, the multi-beam telemeter is used for underwater navigation applications[3][4]. This sensor provides a series of depth measurements along the AUV trajectory. If the terrain contains sufficient information, this sensor can be used to retrieve the state of the AUV using an embedded numerical seabed map. Although multi-beam telemeter aided navigation is able to accurately retrieve the vehicle position, the velocity is often challenging to be precisely estimated. In order to enhance the accuracy of the velocity estimation, we propose to fuse the multi-beam telemeter with an atomic gravimeter [4]. The atomic gravimeter is a promising absolute sensor for underwater navigation. It provides an absolute and accurate gravity measurement. The gravimeter is associated with a gravity anomalies map. This form of navigation is commonly termed Terrain-Aided Navigation (TAN).

Performing INS/TAN fusion makes it necessary to resort to nonlinear filtering algorithms. The state estimation problem is particularly challenging for TAN/INS applications. Indeed, the use of embedded maps involves severe measurement ambiguities (i.e., when measurements may correspond to several areas in the map). In the case of non-Gaussian uncertainty, non-linear measurements, and severe ambiguities, the Kalman filter and its derivatives fail to estimate the state.

Particle filters [6] are an efficient solution to the nonlinear filtering problem since they can, in theory, approximate any posterior density without any hypothesis regarding the linearity of the process or observation model or the Gaussian nature of process and observation noise. However, particle filters are designed to tackle estimation problems where the law of the measurement noise (likelihood) is a priori known. In our case, the likelihood of the multi-beam telemeter cannot be analytically determined.

In order to tackle the issue of unknown likelihood, an Adaptive Approximate Bayesian Computation method was introduced by C. Palmier [4]. A2BC consists of approximating the actual likelihood by a probability density kernel with an adaptive bandwidth. A2BC makes the Monte Carlo methods more robust to measurement ambiguities as the number of estimation non-convergences is significantly reduced.

Furthermore, particles filters based on interval analysis demonstrated promising performances for ambiguous navigation problems and are still an active topic of research (see e.g. Box Particle Filters [7][7], Set-membership state estimation by solving data association [9]). By combining kernel density estimation and set manipulation, they offer remarkable robustness guaranties. The post-doc project will also explore the link between adaptive likelihood approaches and set manipulation particle filters.

The post doc will include an important theoretical part in order to improve the current versions of A2BC particle filters. The bandwidth of the A2BC kernel plays a significant role in the convergence of ABC method [1][2][5]. It would be interesting to link this parameter to the number of particles which would guarantee the precision and consistent estimates of filter.

An experimental part will be planned to validate the A2BC filters. The sensor measurements will come from:

- simulated data from Naval Group test stand ;
- real data collected on a UUV (IMU/Doppler Velocity Log data, bathymetry measurements).

Bibliography:

[1] Ajay Jasra, Sumeetpal S Singh, James S Martin, and Emma McCoy. “Filtering via approximate Bayesian computation”. In: *Statistics and Computing* 22.6 (2012), pp. 1223–1237.

[2] Jean-Michel Marin, Pierre Pudlo, Christian P Robert, and Robin J Ryder. “Approximate Bayesian computational methods”. In: Statistics and Computing 22.6 (2012), pp. 1167‑1180.

[3] Deborah K Meduna. Terrain relative navigation for sensor-limited systems with *application to underwater vehicles*. Stanford University, 2011.

[4] Camille Palmier. “New particle filters for underwater terrain-aided navigation using multi-sensor fusion”, PhD Thesis, 2021.

[5] Pierre Del Moral, Arnaud Doucet, and Ajay Jasra. “An adaptive sequential Monte Carlo method for approximate Bayesian computation”. In: Statistics and computing 22.5 (2012), pp. 1009‑1020

[6] Pierre Del Moral. “Non Linear Filtering: Interacting Particle Solution”. In: Markov Processes and Related Fields 2.4 (1996), pp. 555‑580.

[7] Merlinge, N., Dahia, K., Piet-Lahanier, H., Brusey, J., & Horri, N. (2019). A box regularized particle filter for state estimation with severely ambiguous and non-linear measurements. Automatica, 104, 102-110.

[8] Wang, P., Mihaylova, L., Bonnifait, P., Xu, P., & Jiang, J. (2021). Feature-refined box particle filtering for autonomous vehicle localisation with OpenStreetMap. Engineering Applications of Artificial Intelligence, 105, 104445.

[9] Rohou, S., Desrochers, B., & Jaulin, L. (2020, May). Set-membership state estimation by solving data association. In 2020 IEEE International Conference on Robotics and Automation (ICRA) (pp. 4393-4399).

External collaborations: Naval Group

Host laboratory at ONERA
Department : Traitement de l'Information et Systèmes
Location (ONERA centre): Palaiseau
Contact: Karim Dahia
Nicolas Merlinge
Yannick Bidel

Phone: +33 1 80 38 66 26

Email : karim.dahia@onera.fr
: nicolas.merlinge@onera.fr
yannick.bidel@onera.fr