Strategies development for water quality assessment with Unmanned Surface Vehicles

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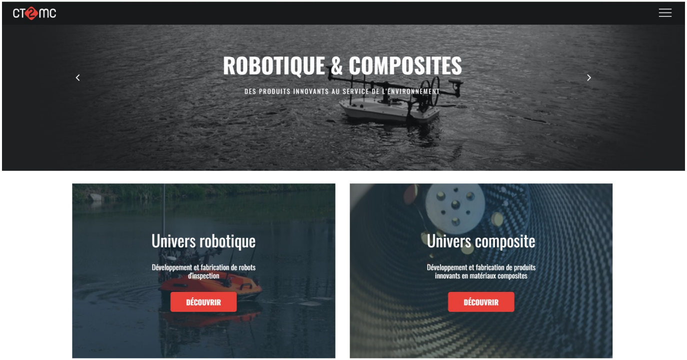


Figure 1: Development of innovative products combining robotics and composites.

Presentation of the SPYBOAT® USVs

Le SPYBOAT® DUCK a été spécifiquement développé pour répondre aux contraintes d'une utilisation dans des eaux calmes et pour les espaces confinés. Ce produit intègre des équipements et des algorithmes de navigation autonome par positionnement GPS. Un pilotage à distance par une interface tablette tactile est disponible pour les opérations de reconnaissance ou d'inspections.

Les caractéristiques du DUCK le rendent facilement transportable sur tous les sites par une personne. Un changement rapide de batterie est prévu afin d'augmenter les capacités terrains du drone lors de campagnes intensives de fonctionnement. Des solutions de transport sont prévues pour les opérations logistiques permettant de transporter en sécurité l'intégralité des composants internes et externes des SPYBOAT®.

Figure 2: Le SPYBOAT® DUCK .

Presentation of the SPYBOAT® USVs

Le SPYBOAT® GOOSE a été spécifiquement développé a été spécifiquement développé pour répondre aux contraintes d'une utilisation en rivière ou en lac. Ce produit intègre une unité de calcul et des équipements dédiés à la navigation autonome par points de passage. La communication avec l'utilisateur est assurée par le biais d'une mallette de contrôle dont l'écran tactile permet l'envoi d'ordres et la création de parcours à réaliser sur site. Ces drones peuvent être utilisés pour des missions de reconnaissance, d'inspection, de monitoring ou d'analyse environnementale. La géométrie du GOOSE a été pensée pour le rendre transportable par une seule personne, ceci afin de pouvoir accéder à des sites difficiles d'accès pour des véhicules classiques.

En vidéo

Figure 3: Le SPYBOAT® GOOSE.

Presentation of the SPYBOAT® USVs

Le SPYBOAT® SWAN a été spécifiquement développé pour répondre aux contraintes d'une utilisation en rivière ou en lac. Ce produit intègre des équipements et des algorithmes de navigation autonome par positionnement GPS.

C'est le plus gros drone de la gamme SPYBOAT®. Il assure l'intégration d'une grande variété de matériels.

Un chariot de transport a été spécifiquement développé pour optimiser le transport du drone sur tout type de terrain.

Dernier né de la gamme : le Swan Lagune équipé d'une perche à sédiments.

En vidéo

Figure 4: Le SPYBOAT® SWAN.

Presentation of the SPYBOAT® USVs

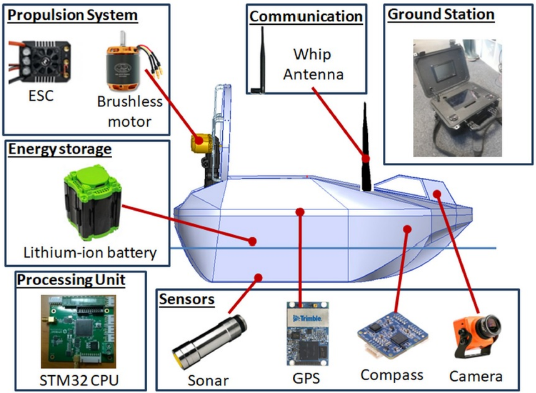


Figure 5: Architecture of SPYBOAT® USVs

USV kinematics and dynamics

In *Hervagault et. al. 2019 Ph.D Thesis* a kinematic model for the SPYBOAT® vessel was identified based on the following standard assumptions.

Assumption 1.1 (*Liu et.al. 2016*)

(i) USVs are moving in a horizontal plane in an ideal fluid. (ii) USV masses are uniformly distributed. (iii) The CG and center of buoyancy (CB) point vertically along the z-axis. (iv) USVs have port-starboard symmetry. (v) Surge and sway-yaw dynamics are essentially decoupled.

In addition to the standard assumptions, the characteristics of the SPYBOAT® vessel allows to consider the following.

Assumption 1.2 (*Hervagault et. al. 2019*)

We will consider the fore/aft symmetry for our system. Considering their flat hull, they don't present any stem for hydro-dynamical optimization. So the Inertial and Damping matrices can be simplified by canceling their off-

USV kinematics and dynamics

The marine craft moves on an horizontal plane and only surge, sway and yaw are considered. The resulting is a nonlinear model given by the following equations.

$$\begin{cases} \dot{x} &= u\cos(\psi) - v\sin(\psi), \\ \dot{y} &= u\sin(\psi) + v\cos(\psi), \\ \dot{\psi} &= r, \\ \dot{u} &= \frac{\tau_u}{m_{11}} + \frac{m_{22}}{m_{11}} vr + \frac{X_u}{m_{11}} u, \\ \dot{v} &= -\frac{m_{11}}{m_{22}} ur + \frac{Y_v}{m_{22}} v, \\ \dot{r} &= \frac{\tau_r}{m_{33}} + \frac{m_{22}-m_{11}}{m_{33}} uv + \frac{N_r}{m_{33}} r \end{cases} \tag{1}$$

The vector (x, y) is the position on the surface and ψ the direction of the vessel, u, v, r are the surge, sway and yaw velocities respectively. The inputs are given by $\tau_u = F_1 + F_2$ and $\tau_r = b(F_1 - F_2)$, where F_1 and F_2 are the port side and starboard side thrust forces.

USV kinematics and dynamics

Figure 6: Le SPYBOAT® SWAN.

Mobile Lab

Figure 7: Mobile Lab.

Validation data

Experiment performed in the Marque River (close to Lille in France) to validate the SPYBOAT® sensors measurements.

Table 1: Comparison between sensors from USV and from field Laboratory.

	Temperature	pH	Conductivity	Turbidity	O_2
Shift	3%	6%	5%	17%	5%
Correlation	0.98	0.95	0.93	0.42	0.96

Intercomparison between the USV on a fixed location and a field Laboratory (static station on the side of the river), performing an online analysis of the physicochemical parameters of the water with a multiparameter probe (Manta+, Eureka Water Probes).

Potential applications for the study and utilisation of USV

Scientific Research:

- Bathymetric survey (*Roberts et.al. 2006*); Ocean biological phenomena, Migration and changes in major ecosystems (*Goudey et.al. 1998*);
- Ocean activities research; Multi-vehicle cooperation (cooperative work among aerial, ground, water surface or underwater vehicles) (*Majohr et.al. 2006*); Experimental platforms for the purpose of testing hull designs, Communication and sensor equipments, Propulsion and operating systems, as well as control schemes (*Breivik et.al. 2010, Vaneck e.al. 1996*)

Potential applications for the study and utilisation of USV

Environmental missions:

- Environmental missions Environmental monitoring, samplings, and assessment (*Caccia et.al. 2005, Naeem et.al. 2008d , Rasal et.al. 2013,Vsvec et.al. 2014*);
- Disaster (like tsunami, hurricane, eruption of submarine volcano) aided Prediction and Management, and Emergency response; Pollution measurements and clean-up.
- Ocean resource exploration Oil, Gas and Mine explorations (*Pastore et.al. 2010, Roberts et.al. 2006*);
- Offshore platform/pipeline construction and maintenance (*Bertram et.al. 2008, Breivik et.al. 2008*)

Potential applications for the study and utilisation of USV

Other applications:

- Military uses Port, harbor, and coastal surveillance, reconnaissance and patrolling; search and rescue; anti-terrorism force protection; mine countermeasures; remote weapons platform; target drone boats.
- Transportation (*Kiencke et.al. 2006*); Mobile communication relays (*Caccia et.al. 2008*); refueling platform for USVs, unmanned aerial vehicles (UAVs), unmanned underwater vehicles (UUVs), and other manned vehicles.

Environmental Missions: Water Quality Assessment

- Briefly we can define the **assessment of the quality of water** as the analysis of physical-chemical-biological parameters, such parameters can provide useful information about the contamination.
- The real-time data acquisition is based on USV which provide the appropriate flexibility to explore sophisticated environments efficiently.
- We are studying strategies to simplify the periodic assessment of the **quality of water** in freshwater resources.

Environmental experiments

Figure 8: Lille, France.

Environmental experiments

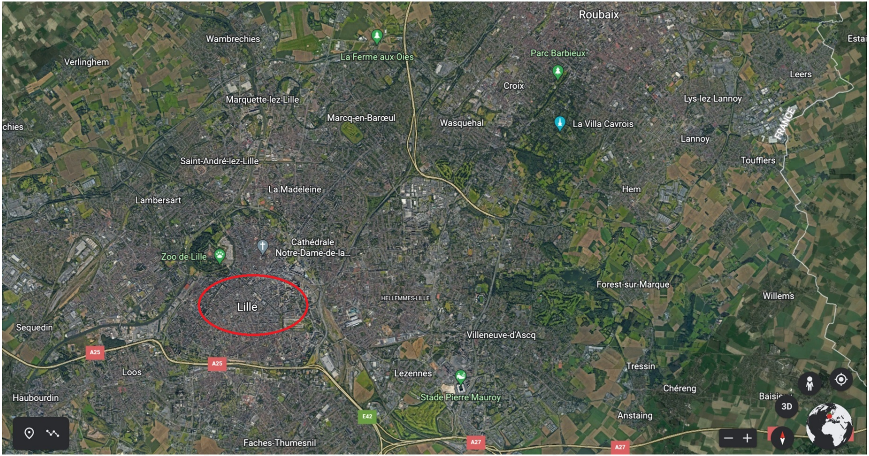


Figure 9: Lille, France.

Environmental experiments

Figure 10: Lac du Herón.

Environmental experiments

Figure 11: Lac du Herón.

Environmental experiments

Figure 12: Lac du Herón.

Environmental experiments

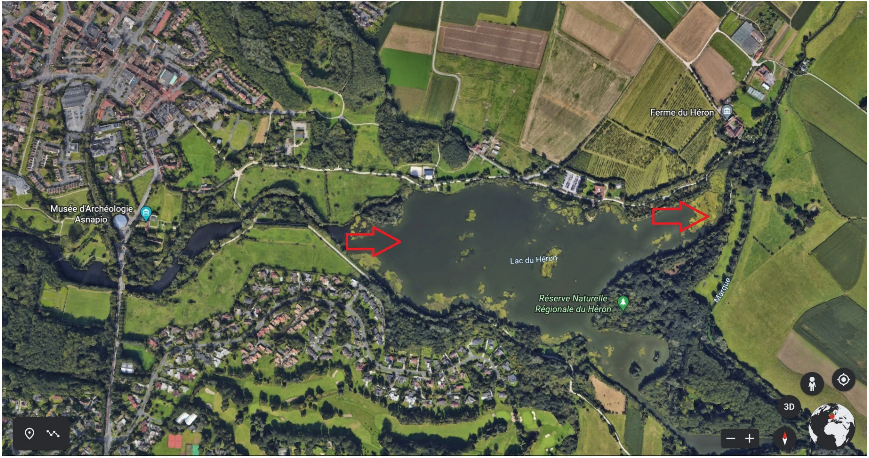


Figure 13: Lac du Herón.

Environmental experiments

Figure 14: Lac du Herón.

Environmental experiments

Figure 15: Sampling area: Measurements were carried out on region Ω on the Heron lake, Villeneuve d'Ascq, Lille.

Environmental mission

To construct a map of the region Ω, i.e., a map $F : \Omega \to \mathbb{R}^5$ such that F assigns to every point on Ω its approximation value of pH, turbidity, conductivity, temperature and dissolved oxygen.

Exploration and data collection of region Ω

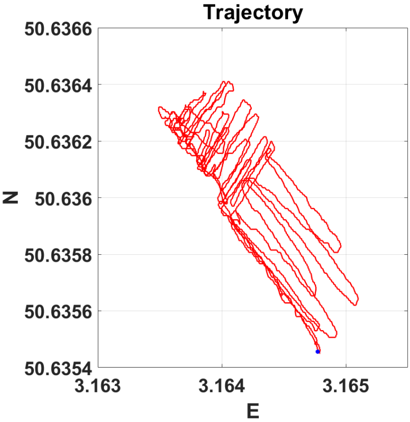
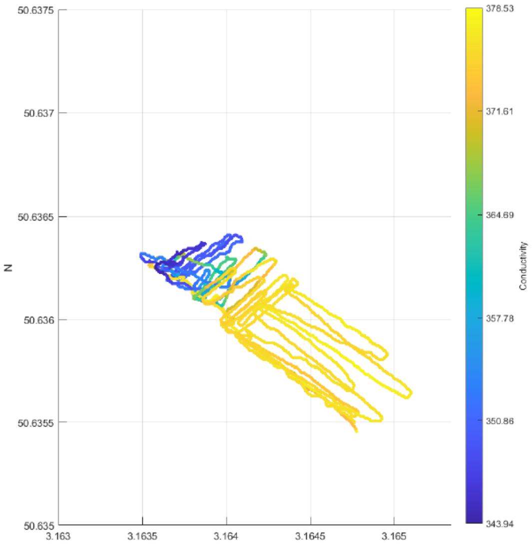


Figure 16: Trajectory of the hand-operated vessel in region Ω with decimal GPS coordinates.

Conductivity



Dissolved oxygen

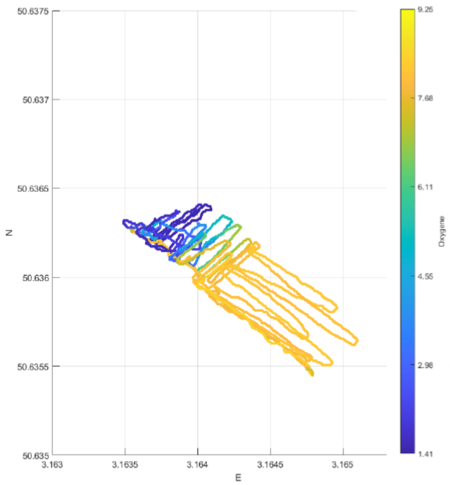
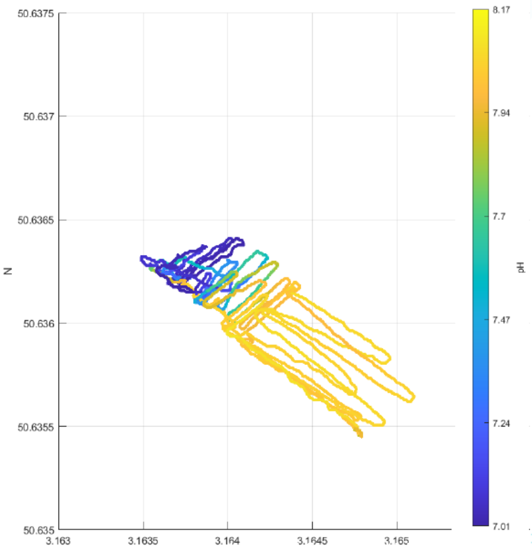
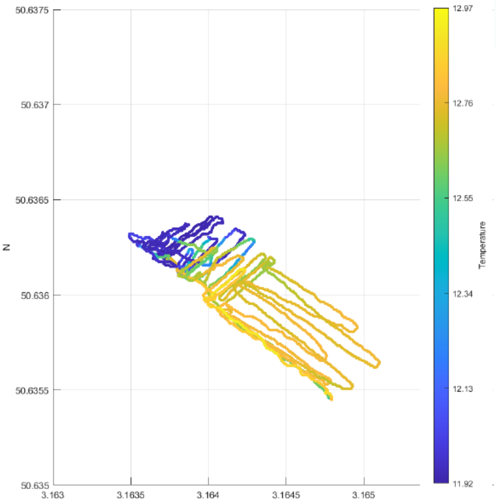


Figure 18: Dissolved oxygen in Ω.

pH


50.6375
50.637
50.6365
50.636
50.6355
50.635
3.163
3.1635
3.164
3.1645
3.165
N
8.17
7.94
7.7
7.47
7.24
7.01
pH

Temperature



Turbidity

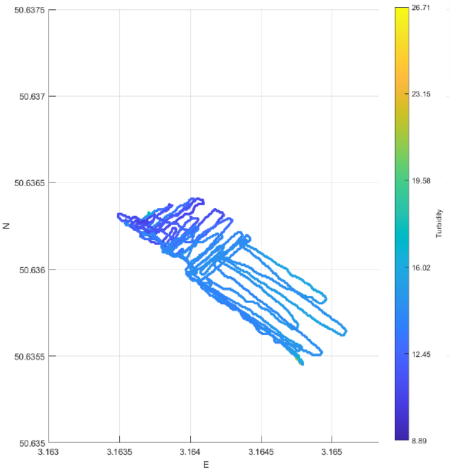


Figure 21: Turbidity in Ω.

Map meshing

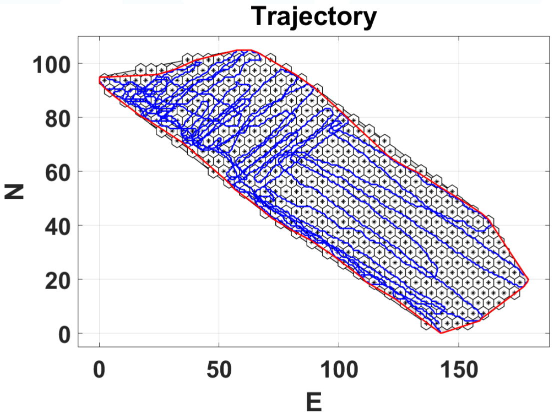


Figure 22: Map meshing with hexagonal Entity E_H with $Sp = 5m$.

Map construction: Kriging approach

- Kriging is a geostatistical interpolation method developed for the *mining field*, which was extended for environmental variables, such as soil quality, wheater temperature, solar irradiance and water quality.
- Kriging strategy uses variograms to relate the distance between the measurements.

Map construction: Kriging approach

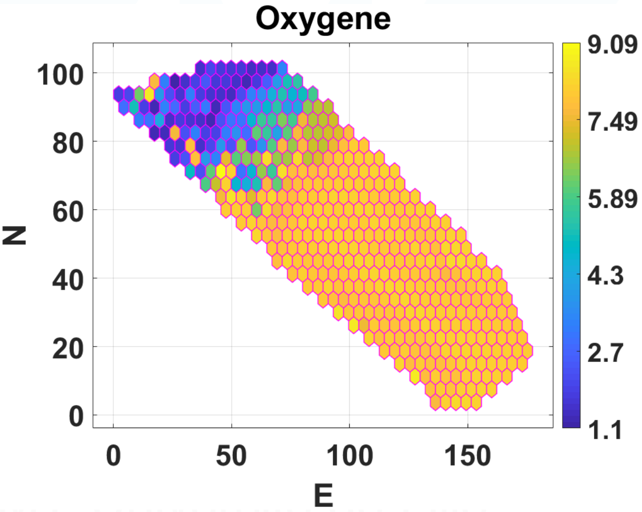
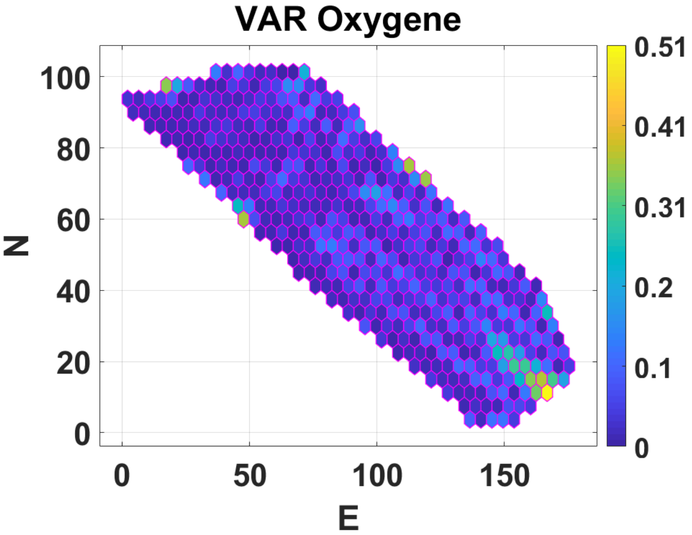
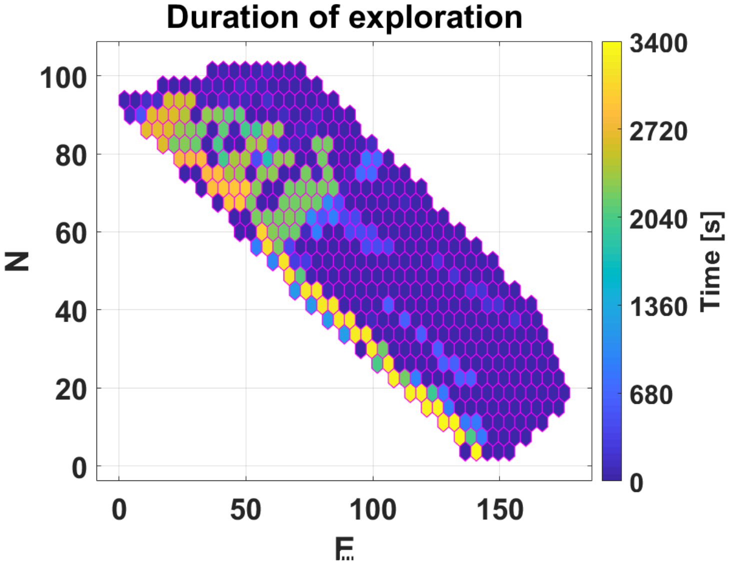


Figure 23: Final Kriging map of DO.

Map construction: Kriging approach



Map construction: Kriging approach



Water assessment

To determine a proper approximation of map F (periodically) there are two options:

- To study interpolation methods to approximate the parameters considering the dynamical of the parameters (spatio-temporal Kriging).
- To develop control strategies to improve the exploration of the region.