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Automation of harmful cyanobacteria blooms monitoring with smart ASVs

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***Abstract* – Cyanobacterial blooms are dynamic biological processes, harmful for the inhabitants and users of water resources, as they can produce highly toxic compounds. The automatic three-dimensional monitoring of waterbodies, supported by smart ASVs (equipped with multi-parametric probes held by a crane, and with positioning, sensing, planning, guidance, navigation & control systems and algorithms) can help authorities to detect them and anticipate decisions to mitigate their risks. This article presents the particular solutions on this approach, currently proposed by the Systems Engineering, Control, Automation and Robotics group of the Complutense University of Madrid.**

***Keywords* –** *Autonomous Surface Vehicles, Artificial Intelligence, Water Quality Monitoring, Trajectory Planning, Navigation & Control*

I. INTRODUCTION

Some species and strains of cyanobacteria produce toxins capable of inducing severe renal, hepatic and neurological damages to the inhabitants, consumers and recreational users of water resources. They become an ecological and public health thread when their populations grow massively, causing Harmful Cyanobacteria Blooms (HCBs). They also change the organoleptic properties of water and accumulate scums on the water surface, shores, and water withdrawal systems [1].

Cyanobacteria complex 3-dimensional dynamical behavior depends on many causes, such as their biological growth, their competition with other organisms, their buoyant capability, the wind, the water currents and eutrophication [2]. They survive hidden underwater, start moving vertically to stay at the appropriate depth when the optimal proliferation conditions are met, and emerge suddenly as HCBs. Altogether makes cyanobacteria detection and prediction challenging [3].

Traditional cyanobacteria monitoring involves collecting manually water samples to determine, later in the lab, the existing cyanobacteria species and cyanotoxins types [4]. This approach lacks the necessary spatial and temporal resolution to anticipate HCBs, at it is only applicable sporadically at few locations of the waterbody. Multi-parametric probes (MPP) located at fixed buoys increase the temporal frequency of the data related to HCB, without providing an appropriate spatial resolution [5]. In contrast, satellite imagery provides periodic information about HCB at the whole water surface, failing due to cloud occlusions and with insufficient temporal resolution to characterize properly HBC evolution [6].

An alternative approach, capable of providing information with the correct spatial and temporal resolution, are Autonomous Surface Vehicles (ASVs, [7-8]). In the following, we will present the more relevant aspects of our particular solution, which consists on equipping the ASV with: (1) a MPP capable of providing data relevant to asses the risk of cyanobacteria; (2) a crane to vertically move the MPP to characterize water columns at different locations of the waterbody; (3) positioning, sensing, planning, guidance, navigation and control systems and algorithms for making the ASV autonomously and smartly perform cyanobacteria monitoring missions; and (4) a Ground Control Station (GCS) to let human operators interact with the ASV and supervise the monitoring mission.

II. SMART ASVS FOR CYANOBACTERIA BLOOM MONITORING

We have designed, developed and automated ASVs since 1997, with the purpose of having platforms that best suits each type of mission (e.g. boom towing, harbour surveillance, or research in ASVs swarms). For HCB monitoring, we have designed and developed several catamarans of moderate size (up to 120 cm long and 30 kg weight), easy to transport to difficult places and capable of navigating on shallow waters. They are equipped with an electric propulsion system (to reduce the water pollution), a positioning system (consisting of a GPS and an inertial measurement unit), a MPP held by a crane (to measure, at different water depths, temperature, pH, oxygen, and chlorophyl and phycocyanin concentration), and an onboard control system (deployed on an STM32 Nucleo-64 digital processor). Examples of our ASVs can be seen in [9] and in Fig. 1a.

The onboard control system (in charge of regulating the ASV horizontal and MPP vertical displacements) and GCS are programmed ad-hoc or reusing part of the functionality provided by Paparazzi [10], which is an open-source software project, originally intended for developing autopilots and GCS for unmanned aerial vehicles and currently under adaptation for terrestrial robots [11] and surface vehicles. In this regard, we have already incorporated into Paparazzi autopilot a guidance and control subsystem to make the ASV follow parametric curves (e.g. cubic splines and Bezzier curves) and stop at their control-points while displacing the MPP vertically [12]. Figure 1b shows a snapshot of Paparazzi CGS with the commanded (in green) and real trajectory (in red) of a recent experiment of the ASV in a small water reservoir.

The planning system consists of different artificial intelligent-based optimization tools, that determine the ASV horizontal and MPP vertical trajectory. In particular, we use a multi-objective constraint genetic algorithm to determine the control-points of the parametric curves to be followed by the ASV and MPP that overpass the 3D locations of the water body with high concentration of cyanobacteria, predicted by different cyanobacteria evolution models and simulators. In particular, [12] considers that the MPP takes measurements at constant-height during ASV displacements and at constant locations during MPP displacements, while [13] considers that the MPP height and ASV location can change during the whole monitoring mission.

Alternative approaches, consisting in reactively controlling the ASV displacements based on the data collected by the MPP, are being studied under simulation [14]. Besides, this approach is only part of a comprehensive framework, also supported by Internet of Things and Digital Twins, for bringing HCB monitoring and decision making closer to water authorities and managers.

III. CONCLUSIONS

We present our current solutions, supported by smart ASVs equipped with MPP held by a crane, and with positioning, sensing, planning, guidance, navigation & control systems and algorithms, for HCB monitoring. Part of these elements are already integrated and under test in real-world experiments while others are being independently analysed via simulations.

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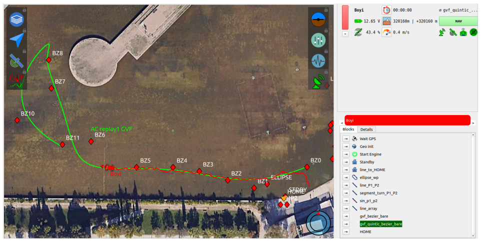
(a) One of our equipped catamarans in the middle of a HCB



(b) Snapshot of Paparazzi GCS during a real experiment

Fig 1. Some elements of our approach

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