Martech 2024.
Marine Technology Workshop
06, 07th June. Palma, Balearic Islands, Spain

# Depth Control Research of µ-Nautilus Profiler in a Real-World Environment

Isabel P. Morales-Aragón[1], Javier Gilabert[2], Roque Torres-Sánchez[1], Fulgencio Solo-Vallés[1]

[1] *Department of Automatics Engineering, Electrical Engineering and Electronic Technology, Technical University of Cartagena, 30202 Cartagena, Spain*
[2] *Department of Chemical and Environmental Engineering, Technical University of Cartagena, 30202 Cartagena, Spain*

***Abstract –*** **The Mar Menor lagoon is a convergence point for various economic and industrial activities, which has significantly impacted its ecosystem over the last decade, leading to episodes fish mass mortality. Addressing this concern highlights the crucial necessity for ongoing monitoring of the water column by scientific groups and administrations. This study focuses on implementing a control algorithm capable of managing the depth in a compact and lightweight profiler called µ-Nautilus, which has the ability to integrate different sensors (oxygen, chlorophyll, electrical conductivity, temperature, among others) to continuously monitor diverse parameters based on specific requirements. An overview of challenges encountered during tests in real environments is presented, along with a comparison of the dynamic behavior and energy consumption of the profiler when implementing control algorithms designed to address these particular challenges.**

***Keywords –*** *Stand-alone profiler, WSN, depth control, process simulation.*

## I. INTRODUCTION

To address the continuous monitoring of a marine environment such as the Mar Menor, a previous study introduced a profiler named s-Nautilus. This profiler, which is currently in use, is capable of monitoring the water column with a configurable sampling frequency ranging from 2 to 24 hours. However, this profiler lacked the ability to control ascent speed and stop at a specific depth. Therefore, a prior study explored different depth control algorithms to enable more precise measurements of relevant variables [1].

The most common options for achieving neutral buoyancy in a device involve the use of thrusters [2] and ballast tanks [3]. However, for the specific application environment in this study, the Mar Menor, the decision was made to avoid actuators exposed to the marine environment due to the prevalence of fouling in this area, making the exposure of external actuators a critical concern. Consequently, this article presents research on various control algorithms that exclusively utilize ballast tanks to adjust the buoyancy of the profiler.

In a prior study, a fuzzy control was examined to stabilize the profiler at a specific depth using only ballast tanks [1]. This fuzzy control was implemented because the ballast volume at each time instant was unknown. However, after numerous tests, it was determined that this controller caused multiple movements of the actuator to reach the setpoint, resulting in increased wear and a reduction in the autonomy of the profiler. Additionally, in real-world tests, situations were identified where this control was not robust enough to achieve effective control in the conditions of the Mar Menor.

This study addresses the various challenges encountered when testing in a real environment with different depth control methods. Furthermore, by adding a Hall effect sensor to determine the ballast volume at each instant of time, the analysis of dynamic response and energy consumption of various control algorithms meeting the specific requirements of this marine environment is presented. Tests were conducted in real conditions with a new prototype, half the size of the s-Nautilus profiler, named µ-Nautilus, which is more compact and lightweight, facilitating transport with a single operator. This profiler relies solely on a 750 $cm^3$ ballast tank to adjust its buoyancy.

## II. MATERIALS AND METHODS

### a. System modelling and controller design

The system is modelled using equations that define it, considering factors such as thrust, weight, hydrodynamic force, and actuator behavior, aiming for a representation as realistic as possible. Subsequently, the controller is designed, seeking fast dynamics without significant overshoot and minimizing error.

### b. Laboratory tests

Experiments are conducted in a tank measuring 2 meters in height and 0.5 meters in diameter at the Technical University of Cartagena to verify the appropriate control dynamics.

### c. Real-world testing

These tests were conducted at “Real Club de Regatas” yacht club (Cartagena), which has a depth of 5 meters. In these tests, the ability of the controller to track the reference signal is assessed, even in the face of challenges outlined in section III. Additionally, control dynamics are examined, and the energy consumption required for each control hypothesis is studied to verify compliance with the autonomy specifications of the profiler.

## III. RESULTS

### a. Challenges encountered in a real-world environment

When linearizing a system, that is done around an operating point, which in this case is determined by the weight of the profiler. This profiler was designed to be flexible and accommodate different sensors, so each addition of a sensor alters its weight. Furthermore, variations in weight due to fouling in the Mar Menor must be considered, demanding that the control be robust against changes in the operating point.

During tests, it was observed that the profiler sometimes became anchored to the seabed, making its ascent challenging at the beginning of control. Additionally, ocean currents caused movements that distorted the perception of buoyancy, generating disturbances in control. Therefore, the control system must effectively handle these situations.

### b. Control hypotheses

Following the tests, two control hypotheses to address the mentioned issues are identified, based on a cascade control approach, where the inner loop manages the speed, and the outer loop controls the depth of the profiler.

In the first hypothesis, a conventional cascade control is employed with the ballast tank operating over its entire range. Although it allows for disturbance control, the slowness of the actuator causes it to oscillate around the neutral buoyancy point, generating numerous oscillations. Consequently, it results in an absolute error of 20 cm and an average actuator runtime of approximately 170 seconds when performing controlled ascent to four depths.

Conversely, the second hypothesis utilizes a cascade control with a limited actuator range around the operating point. This reduces oscillations, decreasing the absolute error to 10 cm and lowering the average actuator runtime to approximately 60 seconds during controlled ascent to four depths. To adapt to changes in the operating point, the calculation of this point is performed at the beginning of each control cycle, avoiding the need to redesign parameters for modifications such as adding sensors or changes in weight due to fouling. However, calculating the operating point, especially in the presence of disturbances, could introduce additional times, slowing down the cycle execution and increasing energy consumption.

## IV. CONCLUSIONS

This study focuses on analyzing control algorithms designed to overcome specific challenges in real-world environments. A comparison of the dynamic response and consumption of two control algorithms addressing these challenges is provided. While the first hypothesis is based on a traditional cascade control, easy to implement, the second hypothesis stands out for a more damped control dynamics, lower steady-state error, and lower energy consumption. Although some of these parameters may not be as satisfactory in certain situations, this second hypothesis adapts more optimally to the specifications required for the profiler, thus concluding as the most suitable design among those presented.

## V. ACKNOWLEDGEMENT

This study formed part of the THINKINAZUL programme and was supported by MICIU with funding from European Union NextGenerationEU (PRTR-C17.I1) and by Fundación Séneca with funding from Comunidad Autónoma Región de Murcia (CARM).

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