# Optimized Adaptive Control on Dual Buoyancy System for application in Underwater Gliders

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***Abstract:*** *The control on the navigation and guidance procedures applied to underwater gliders are based on the combination of the effect of variation of the vehicle buoyancy in association with internal masses movements. The buoyancy control subsystems of most common commercial gliders are mostly based on oil fillable external-bladders which can increase the vehicle net volume in a small amount of near ±0.5-0.8%. Movable internal masses are used for attitude control of the vehicle. Nevertheless, most of these systems generate low values on the vehicle dynamics which make difficult the use of low cost navigation sensors because high level of noise and low accuracy. With the aim of advance in the use of off-the-shelf electronic components for application in the control of all the previous mentioned subsystems, it has been designed a multistate control for application in the underwater glider Alba-14. Because the moderated values of accuracy of low cost MEM electronic sensors considered, it is considered this system for application in gliding based underwater vehicles with higher dynamic capabilities than the standard ones. A multimode hybrid control system associated to the multiple buoyancy based propulsion technique implemented in the Alba-14 glider is proposed in this paper.*

***Keywords:*** *Hybrid Underwater glider, Adaptive Control, Marine Robotics, Arduino, AUV.*

## I Introduction

Several methods have been implemented for application in the control of navigation of underwater gliders. Because their particular system of propulsion based on variable buoyancy, these kind of autonomous vehicles have special characteristics that require specific methods of control. Heading angle is controlled in some designs by the effect of roll angle in combination with surge speed and a certain angle of attack [1]. Since no direct speed measurements are usually available, estimations by the application of observer-controller combination should be applied in base of the measurements from the Inertial Unit (IMU) integrated gyro and accelerometers. These sensors provide rotational velocity in three axes but due the low maneuvering velocity of gliders, high level of noise in the measurements can mask real values and provide erroneous feedback to the controller. On the other hand, and because their particular propulsion system based on variation of vehicle buoyancy (±0.2 Kg), effective surge velocity and the consequent horizontal crossing-sea effective travel can only be obtained by conducting saw-toothed trajectory during underwater navigation. By means of different heading control systems (roll attitude control by internal moving mass or movable tail fins), underwater gliders can adjust their heading for following the desired course [1]. However, these techniques of steering are conditioned due to the mentioned reduced speed and dynamics. As a consequence, low effect of hydrodynamic forces on the vehicle usable for maneuvering. With masses of 50 kg around on most common gliders [1], a variation of buoyancy to mass factor of 0.4-0.8 % and low effective velocities of 0.25 m/s hydrodynamic forces reach low values during maneuvering and navigation.

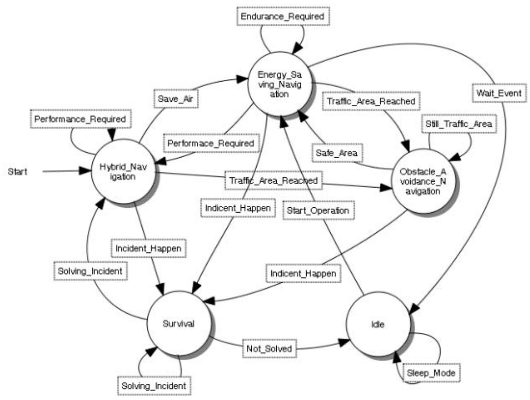


Fig. 1 Example of multistate model for application in the adaptive control system of the Alba-14 Glider.

This low ratio impel to limited rotational and lineal velocities which can greatly affect to the stability of the vehicle trajectory when even moderate external disturbances arise. The importance of appropriate sensor instrumentation onboard is evidenced when it is observed the effect that a faulty or badly calibrated sensor [2] can produce in a gliding-based underwater vehicle. An erratic and uncontrollable response by part of the vehicle can be expected in this last situation.

In addition, the control of buoyancy system by using off-the-shelf control sensors has extra problems associated to the level of accuracy and technological features of the low cost components considered. For dealing with these limitations, adequate robust adaptive control procedures should be developed (fig. 1) in order to minimize the effect of the high noise level present in the inputs, and the leakage of accuracy associated to off-the-shelf sensors considered.

**II Multimode Hybrid Control**

For dealing with different situations along a simple medium/long term mission for a medium/long range glider, a multimode hybrid control has been designed for application in the hybrid underwater glider Alba-14 [3]. Several unexpected events can be predicted to be encountered during long range navigation especially near coastal areas. However adaptation to a specific feature or event of interest requires modifications on the navigation parameters and the vehicle behavior by means of the application of a deliberative control framework [4]. These modifications on the plan become easier in case of standard propelled vehicles (AUV) because their increased capacity of maneuvering and controllability, especially in short term/short distances [5]. Hybrid propeller gliders could deal temporarily with these situations but for a limited period of time and only depending on the internal power reservoir devoted to propelled propulsion [6]. In our case and although high environmental variabilities are among the events to deal with in a prospective mission, human activities at sea may be most serious interference with the vehicle plan.

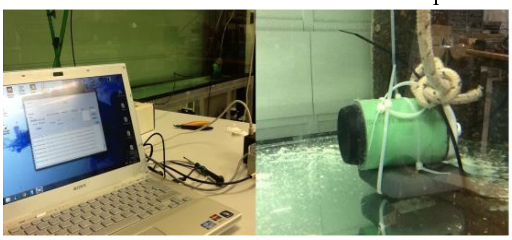

Fig. 2. Set up for testing in a UPV-lab the acoustic communications capabilities of the Alba-14

For minimizing the associated risks to these particular situations (commercial navigation, fishing trawling etc.) an appropriate procedure detection based on underwater acoustic (fig. 2) will trigger a prioritizing reaction for self protection.

The detection is based in this first stage of the project, in the identification of specific frequencies and level detection with directional capacity based on the underwater environmental sound received from a set of converted low cost hydrophones as acoustic sensors [7]. In case of a risk of impact would be assessed, an obstacle avoidance mode with maximum priority overlaps on the other states on the mission and trigger a detection-and-run-away procedure (Fig 1). This procedure can derive in a specific idle mode keeping the vehicle in the sea floor in areas of low depth, where no deep navigation is possible. The vehicle can remain in this situation until the external source of sound is identified as of low risk for continuing its mission. In other situations related with marine high energetic environment is when an improved buoyancy control can be of great interest. Higher vehicle dynamic capacity associated to a variation of ± 0.5 Kg representing a 2.8% of the vehicle mass can impel to the glider with higher dynamic capacity in the upper layer of the water column. Keeping an acceptable value of autonomy can increase their possibilities of dealing with areas of complex marine dynamics. Some of these conditions may be forecasted and modeled for both marine traffic density and current pattern in the area of navigation. Other critical scenarios where turbulent water mixing and associated fluctuations are present can take advantage from a self-adaptive behavior. Areas near river mouths, navigation in fiords during seasons of melting ice, or high density saline plumes coming from inland saline lagoons [8].are among others some of the situations with increased difficulties for underwater gliders. In some of these cases is when the mentioned increased dynamic capacity by part of the vehicle can be of interest for having success. Increasing the spatial and temporal resolution by multiplying the sampling ratio can reduce the latency in obtaining data at a for example, a mesoscale level survey. In addition, the possibility of using a water sampler unit [9] can be benefited of an improved velocity of navigation, by allowing a higher frequency analysis of the samples and thus, a quick reaction. This feature can be very useful when high evolutional events like Harmful Algae Blooms (HAB) are detected in the transition phase or in their initial stages.

### III Main Microcontroller and peripherals based on Arduino© open source platform

From the first application on the Alba series of glider vehicles, the control of internal functions has been based on Arduino and compatible boards.

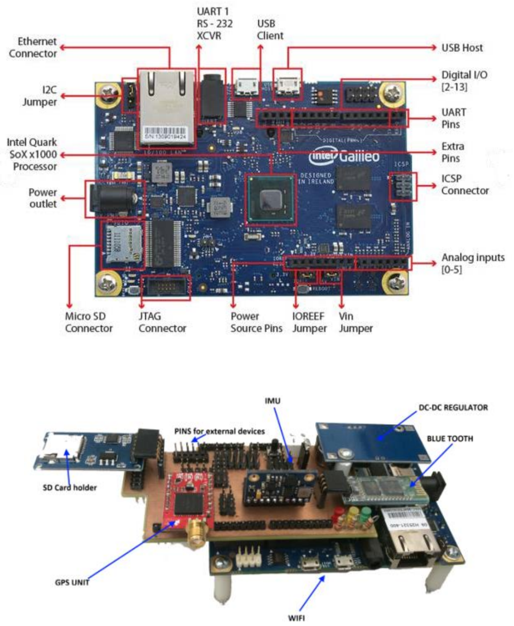


Fig. 3 Intel Galileo Arduino compatible board for improved computing features and self-supporting multimodule shield designed for easy replacement and quick component debugging.

This open source platform and its associated devices and peripherals have demonstrated their feasibility even for application to complex projects [10][11] Several are the advantages of using Arduino as a control platform in underwater vehicles. Testing this platform in underwater vehicle applications [12] has contributed in gaing confidence for apply it to further designs based on this platform [10] and in some interesting educational projects [13]. Due to the high number of users and because its concept based on open source, the success of Arduino systems gave to count with millions of users worldwide that can contribute to improve routines and libraries and sharing knowledge in further related designs.[14][15]. The fact of sharing information among Arduino users, represent one important advantage for all the community since improvements in sensor applications can benefit to other members of the group. In base of that last, important advantages related to the open source concept, have been applied since first prototype of the Alba propelled underwater vehicle [12] A compact shield for with Arduino pinout pattern has been designed for this project allowing to keep in a simple unit all the electronic modules and sensor electronic units (fig. 3). Advances computing features as EKF on input signals are feasible with this hardware configuration (fig. 4)

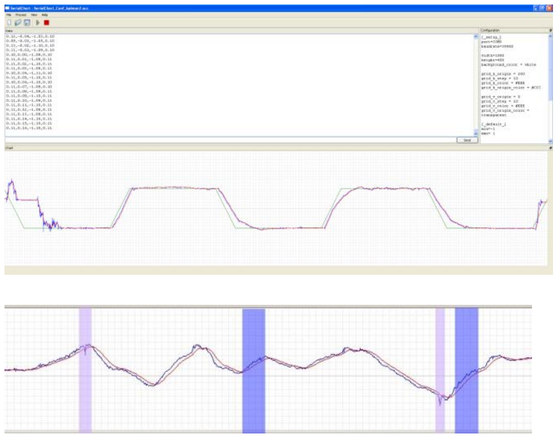

Fig. 4. Extended Kalman filtering (EKF) processed by Arduino mega 256.. Direct measurement data output from the IMU (up). Detail of filtering in Pitch (θ) angle signal with frozen signal (purple) and high noise level (blue) (down)

showing a sensors module GY-80 used in this project which provides an acceptable answer to the input signals.

### IV Adaptive navigation pattern to external conditions

Adaptive control is intended to be applied in the Alba-14 vehicle for providing its capacity for self-managing with external unexpected events. Obstacle avoidance in regions with dense marine commercial traffic is one of the most important cases that should be taken into account. Evasive manoeuvers or change in the dual engine alternation of pattern should be taken autonomously. Other situations like navigation in areas where iceberg encounters are frequent as north latitudes and Antarctica, add difficulties to deal with due to the need of active systems of detection. In the first stage of the project, it has been only considered passive acoustic detection by hydrophones for identification of surface marine traffic. The detection is based on the noise produced by the engine propulsion system of standard vessels and their characteristic frequency

Several test are being conducted for assessing the capacity of low cost hydrophone and a commercial high frequency transducer, operating together with a powerful Arduino based microcontroller (fig. 3).

Although it is expected and interesting effectivity on the proposed evasion procedures it still remaining a certain risk in cases of to undetectable underwater ships and sailing boats. Nevertheless the possibility of having a dangerous encounter in open seas with these marine crafts is considered marginal

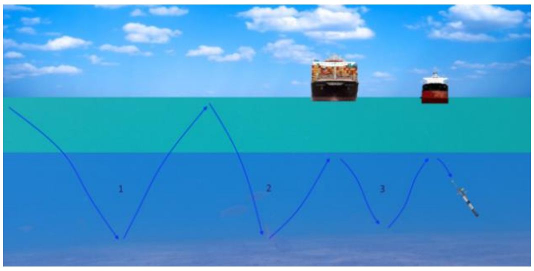

Fig. 5. Point 1, combined dual fluid buoyancy based navigation. 2 Surface traffic detection, switch to deep navigation mode

The proposed adaptive procedure is based on several modes of operation. One of them, taking advantage of all the water column high up to the maximum rated depth. This mode, as a sea surface sewing-like navigation pattern (fig. 5.) can improve the distance travelled by applying dual buoyancy methods[3].

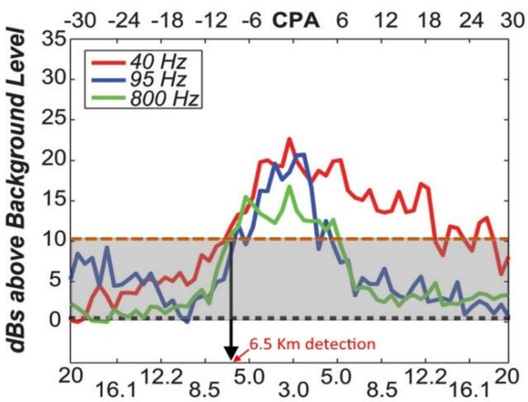


Fig. 6. Example of underwater noise pattern from a survey of M. McKenna et al [16] container shows that a threshold of 10 dB allow to detect a passing ship at a safe distance.

An additional mode of navigation and intended for vehicle self-protection as it has been previously mentioned, will consist in keeping the vehicle in safe depth for crossing the areas where surface marine traffic is detected (fig. 5).

This detection could allow the vehicle to trigger an evasion manoeuvre by conducting the next transect in deep mode. Since low cost components based on Arduino platform are considered in this project, a low-cost hydrophone like it is detailed in in the Seaperch project [17] for application in close detection. It will be used a better component [18] than proposed in the previous work for increasing the sensitivity in the maritime traffic detection.

Although this device will still be an off-the-self grade microphone, converting it into a low cost hydrophone should provide improved features with respect the original project [17].

- Sensitivity: -35dB ±4dB
- Impedance: Less than 2.2kΩ
- Omnidirectional
- Frequency: 20Hz to 20kHz
- Supply voltage: +3V standard; +10V maximum
- Current Consumption: 0.5mA maximum
- Sensitivity Reduction: -3dB @ 1.5V
- Maximum Sound Pressure: 114.5 ±10 dBSPL, approximately
- Signal-to-Noise Ratio: 60 dB

Fig. 7. Microphone for robotic application from [18] as noise sensor for surface ships detection.

A reduction in the detection distance of 1/3 will be acceptable since 2 km of margin will provide time enough to the glider for reaching a saving depth considering a ship speed of 11m/s (fig. 6).

## V Conclusions

The applications of low-cost components and *of-the-shelf* devices can be useful even for advanced applications when not extremely high level of accuracy is required. An optimized adaptive control system based on multiple states can be implemented for using these components in an Arduino compatible microcontroller and off-the-self components. This configuration can be useful for dealing with different situations in medium/long term deployments for massive oceanographic surveys. Nevertheless and although MEM components can afford an acceptable level of accuracy, low cost devices are still far away of more accurate and expensive instruments, especially with respect to angular velocity and acceleration measurement accuracy and noise level. These measurements are essential for vehicle pose estimation and dead reckoning navigation when no GNSS positioning is available during submerged navigation. However, low cost acoustic sensors considered in this project (fig. 7) in combination with an appropriate set of the last generation development microcontrollers like the Intel Galileo board, can provide important improvements as a testbed for applications of advanced navigation control systems. An adaptive navigation schema can be performed in base of low cost sensors and microcontrollers based in Arduino open source platform like the proposed combination. Intel-Galileo and low-cost hydrophones and an adaptive multimode can provide an acceptable margin of safety for the vehicle performing external traffic detection and identification

### VI Future work

Future works include the implementation, simulation and real test of all modes of operation of the vehicle and autonomous transitions among the established modes of operation. Tests and trials with the prototype of the Alba-14 glider in confined environment are scheduled for this year. Additional open water trials are expected to be conducted as well. These real field tests will be oriented to assess the vehicle behaviour by exposing the glider to different prospective in real operation situations, and checking the behaviour and vehicle response. An additional goal will be the validation of the concept and electronic platform and adaptive control proposed and the cornerstone for further improvements in range, autonomy and autonomous response.

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