Low-cost AUV based on Arduino Open Source Microcontroller Board

for oceanographic research applications in a collaborative long term deployment missions and suitable for combining with an USV as autonomous automatic recharging platform

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***Abstract*— The challenge of extending the autonomy in AUV deployments is one of the most important issues in oceanographic research today. The possibility of maintaining a team of AUV under deployment in a defined area of interest for a long period could provide an additional source of information [8]. All this data in combination with the measures provided by buoys and sea gliders used for slow motion and long range operations will be very valuable. A group of low cost AUV's in alternative automatic switching system navigation-charging operation, could allow a kind of continuous surveying operation. This work is the continuation of the ideas that some of the authors previously presented in the AUV 2010 conference at MBARI [8]. At this conference was proposed the great interest for researching oceanic processes on two areas near Cartagena, Spain: cape Tiñoso and the Mar Menor a shallow coastal lagoon. Both areas require a different research structure configuration because of their opposite characteristics. The Mar Menor is a shallow salty lagoon 20 miles long with 7 m of maximum depth and particular features. This lagoon seems to present a sort of oceanic behavior and can be compared with the major oceans but a minor scale. The second area considered is cape Tiñoso, a very deep area in the Mediterranean Sea where the presence of a self-break provides an interesting potential for the research of the effect of upwelling currents.**

***Index Terms*—AUV, automatic, long term, low cost submersible vehicle, Arduino, oceanography, underwater vehicle, vehicle autonomy, distributed computing, low cost AUV.**

I. Introduction

In this paper we present a first approach in the design of a low-cost AUV, capable of accomplish different missions adapted to the special characteristics of the Mar Menor environment and the Cartagena area coast [8]. A design suitable for applying in long-term deployments is essential due to the unpredictability of some interesting phenomena in these areas. A low cost AUV suitable for multivehicle deployments will be proposed. Several tests on some parts of the vehicle are been carried out in order to validate this new and inexpensive device. The utilization of low-cost elements on the body, motor and electronics as it is the aim of this project, could reduce significantly the final cost of construction of the AUV. This reduced cost will allow the possibility of having a set of vehicles instead just one unit for applying to the desired research missions. The features of this low-cost vehicle will not be obviously at the same level than other AUV's available today on the market. A surface autonomous vehicle will be proposed as the AUV recharging dock station and will be developed in future works. Initial tests of different components are being conducted this summer and the prototype final assemble is expected for the end of the year.

This project is the result of a cooperation among a group of students of Naval Engineering from the Universidad Politecnica de Cartagena and Universidad Austral de Chile and students of computer science from the Universidad Politecnica de Valencia. These students have been supported by PhD. professors from all mentioned universities.

II. Electronic control

The aim of this project is to carry out an AUV able to perform an autonomous point-to-point trajectory using control sensors and actuators to arrive to its objective. For this purpose, electronic control has been developed based on *Arduino Mega* with the required analogue and digital electronic to integrate all the elements: sensors (pressure, accelerometer, gyroscope and compass), actuators (servomotors) and power electronic for motor switch [4].

A. Hardware description

All the electronic elements are governed by the main board *Arduino Mega*. Peripheral devices for the sensors are a

GPS (*Venus GPS*) to take position and a module which integrate accelerometer, gyroscope and compass all in one (*IMU Razor 9*). *Arduino Mega* uses an *Atmel* 8 bits microcontroller: the *ATmega 2560* with 256 KB Flash memory, 8Kb SRAM, 4Kb EEPROM and 16Mhz of clock frequency. *Venus Gps* provides GPS frames to the microcontroller at 9600bps via RS232 serial transmission. Frequency updates arrives up to 20 Hz and takes 29 second during cold start consuming close to 67 mW in navigation mode. Accuracy is about 2.5 meters. Other sensor module, the *IMU Razor 9*, gives us three dimensions in each sensor: accelerometer ADXL345, gyroscope LY530ALH – LPR530ALH and compass HMC5843. All information taken from sensors are processed by an Atmega328 8 bits microcontroller in the same PCB board and and it is sent via serial to the Arduino board at 38400 bps. The resolution of each sensor is as follows: for gyroscope 300º/s, for accelerometer 13 bits and +/- 16g, and finally for compass 7 mG and +/- 4 Gauss.

B. Design description

The AUV has the following characteristics: two rudders, depth and drift, with no lateral flippers. Both rudders are controlled by 5 Kg/cm servomotors. The engine works with 12V batteries and has two gears, one slow and other faster. To switch the main motor, the electronic uses power-mosfet or mechanical relays. To adequate the voltage for the different devices it uses DC-DC switches LM2678 to improve energy consumption efficiency up to 92% with different voltages: 3.3V for peripherals, 5V for Arduino board and 12V for the engine.

The total AUV longitude may vary at produce time depending on the number of batteries to be allocated in the middle of the body.

C. Control processing

The actuators are controlled by a PID regulator [2,3] based on the sensor information (Fig. 1). The regulator is controlled by three parameters: Kp, Ki and Kd, corresponding to the proportional, integral and derivative error. They are settled by means of tests. The result of the calculations are translated into actions for rudders and the engine gears whose will perform changes to avoid deviations on the trajectory as much as possible and arrive to each predefined point with a certain precision without making an unstable route [1].

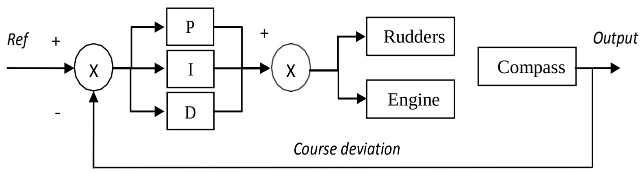


Fig. 1. PID controller.

D. Algorithm

The algorithm (Fig. 2) starts with a well-known route interpolated by points in DMS coordinates (grades, minutes and seconds) or decimal coordinates. From the initial point, the AUV takes the exact position from GPS on surface and establishes the course in degrees to arrive to the next point using compass. After that, it is immersed till to a determined depth in which control regulator acts to maintain the desired course calculated in surface. When a certain time is elapsed or a distance is covered, the AUV emerges and checks on the surface its position with GPS relative to the expected objective and makes corrections in the course. This correction may produce changes in engine speed once the submarine is immersed, if it is necessary to arrive to the point tolerance. During navigation, AUV will collect the desired measures and store them in flash memory. This process is repeated up to get the final point of our route (Fig. 3). Once there, it will stand on the surface. Obtained data will be taken from the microcontroller card memory to be processed.

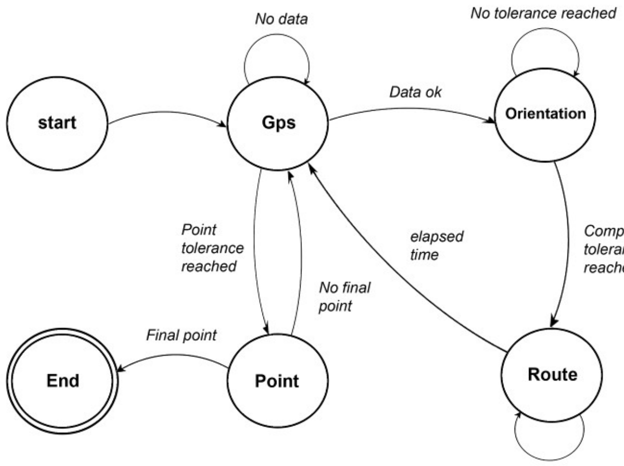


Fig. 2. AUV´s states.

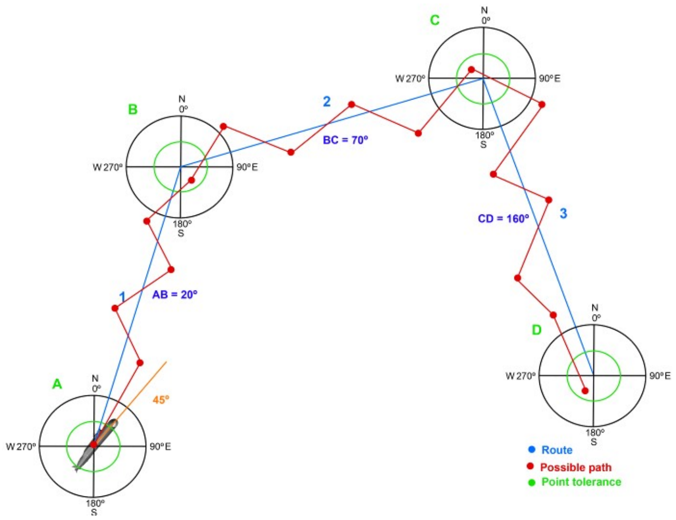


Fig. 3. AUV route example.

E. Testbed

At this moment, control is emulated by a prototype board which contains sensors and actuators (Fig. 4). Tests are realized on the ground on a mobile chassis. LEDs indicate the state of our device and the actions performed. The final aim is to correct and adjust parameters to minimize error on the real environment underwater. Finally all devices will be mounted on the AUV when the totally of its components be tested and made.

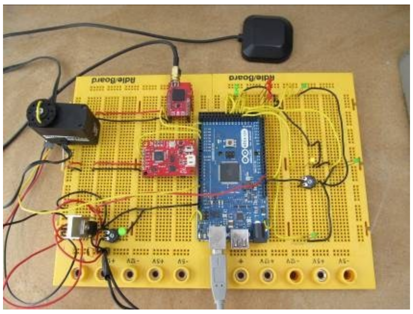


Fig. 4. Protoboard.

II. OCEANOGRAPHIC AREAS OF INTEREST

The coast of Cartagena Spain, is very diverse and active area from many different points of view. It presents interesting geological, physical and biological features that makes it a singular area for research. Located on the South Eastern coast, by the Mediterranean Sea, 37º 40´N, 0º 50´W it is at the spurs of the Alboran Sea drawing the border between the Atlantic Ocean water coming in through strait of Gibraltar and the Mediterranean water, with higher salinity. The Cape of Palos, with one of the oldest Marine Protected Areas (MPA) of the Mediterranean sea is the area separating two different and well defined submarine areas. North of the Cape of Palos there is a wide and highly rich continental platform where a pockmarked field containing holes of 200-800 m diameter has been recently found a. This pockmarked located at 20-60 m of depth. [2] (Fig 5.)

This field is located in front of the Mar Menor Coastal Lagoon (MMCL), the largest one in the Iberian Peninsula, and one of the largest in the Mediterranean Sea. The Mar Menor has a surface of 135km^2 with an average of 4,0 m depth where a maximum of 7 m. can be found in some points. The exchange water process with the Mediterranean Sea through a system of shallow is one of its more interesting characteristics [8]. The residence time of the Mediterranean water into the lagoon has been calculated on one year about. Due to evaporation exceeds precipitation and runoff this lagoon contains hypersaline water of (47 – 52 P.S.U.). Compared to the salinity of the Mediterranean Sea (36 – 39 P.S.U.) the different density promote some interesting effect related to the flow-in flow-out process near the inlet channels.

Fig. 5. Pockmarks in front of the Mar Menor Coastal Lagoon.

Biologically, the Mar Menor lagoon works as a very singular system because it works as a buffer for the salinity adapting process on many species. It has physically stressed system that pushes species to adapt themselves to a changing environmental between in and out the lagoon. The influence of the coastal lagoon water going out to the Mediterranean Sea was chosen as a case of study to develop the first Autonomous Underwater Robotic Experiment in the Mar Menor Coastal Lagoon in 2011 [9] This was an AUV based multi-vehicle collaboration experiment [10] evidencing the need of longer autonomy vehicles to detect the saltier plume of water at very high spatial and temporal resolution.

South of the Cape of Palos, the absence of a continental shelf brings depths of more than 2500 meters at less than 8 miles from the coast. With several submarine canyons, the one at Cape Tiñoso is well known by local fishermen due to the important fisheries produced by the upwelling currents in the shelf-break at the mouth of the canyon. This study requires much of the experience gained in the AUV Underwater Robotic Experiment in the Mar Menor Coastal Lagoon [10] as well as deep water vehicles combined with both deep and shallow buoys. Obviously, a single vehicle cannot afford this study on its own, being needed a collaborative team of vehicles for long term survey. This requires finding a practical solution to provide autonomy and energy sources for semi-permanent deployment for all the vehicles involved in future experiments.

Fig. 6. Areas of interest near Mar Menor

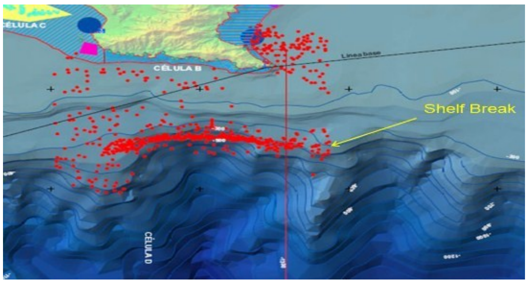


Fig. 7. Shelf break area off cape Tinoso

Due to the important differences among all previously mentioned areas of interest, it will be a special challenge the design of an adaptive AUV suitable for all of them [7]. The difference on depth from 7 m in the Mar Menor; 15-60 m in the saline plume and pockmarks area and the 200 to 2.500 m of depth off cape Tiñoso affect to the design of an AUV adequate for these different places with so different physical conditions. The possibility of reaching all these areas using a fleet of robust, inexpensive and simple vehicles minimizes the financial consequences in the case of lose or damage, and thus the risk of undesired interruption on the survey.

III. AUV DESIGN

The vehicle design characteristics are the following: The watertight hull is a cylinder made in INOX. The cylinder is placed in the middle section, where a fiber glass external coverage, reinforced in base of a tubular longitudinal structure made in Aluminum that provides to this section additional straightness.

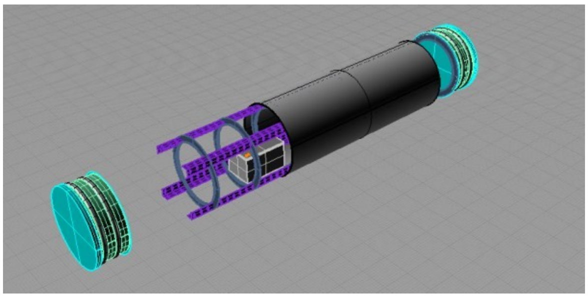


Fig. 8. Mid section assembly showing internal structure and closing

This configuration allow for using interchangeable middle sections of different length, depending on the special requirements of each mission. Different length on the middle section means more room for batteries and thus the extension of the AUV range and autonomy. The fore section coverage is made in fiber glass in different shapes depending on the experiment particularities and the special needs of the instruments placed in. An internal structure in this section provides support for instruments and for fixing the nose hydrodynamic coverage. The aft section is made in a similar way the front one. An square structure in aluminum serves as a support for the motor and gives room and support for the horizontal tail planes and rudder actuators. The rear section is covered by two conformed blades finishing the hydrodynamic hull. These blades as the rest of the external hull are made in fiber glass but without metal structural internal reinforcements in this case. The aft section supporting structure is reinforced in order to provide straightness for the extra weight provided by the motor. An area is reserved both in fore and aft sections for housing the variable buoyancy system bladder. A 1.2 meter length mast is an optional element in the rear section for providing a higher over the sea surface location for the antennas group unit, in order to guarantee a good communication even when operating in rough seas

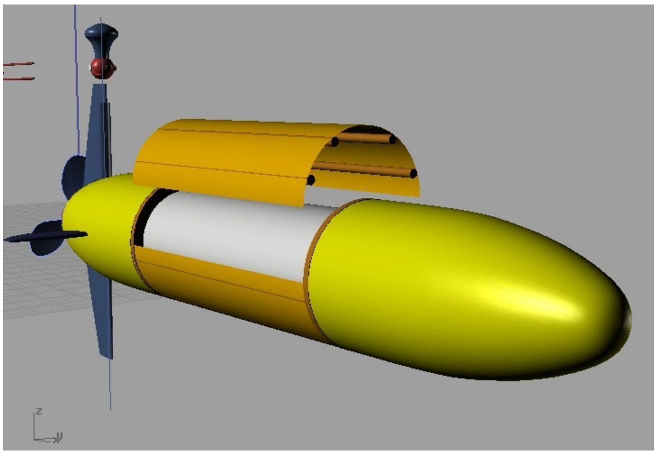


Fig. 9. Top cover open for battery mid section access

A. AUV CHARACTERISTICS AND DISPOSITION

One of the main goals of the design of this AUV is to obtain a flexible and easy-to-reshape device. This is one of the reasons why the vehicle has been designed in three main bodies: nose section, medium section and rear section. Each section is easily removable for replacement or maintenance purposes. The nose section contains part of the scientific elements, navigation instruments and sensors. The middle section provides a watertight area for giving house to the batteries set and electronics. The aft section includes the propulsion system, main motor, stabilizers and actuators. Some experiments, sensors and sample containers system can be installed in this section.

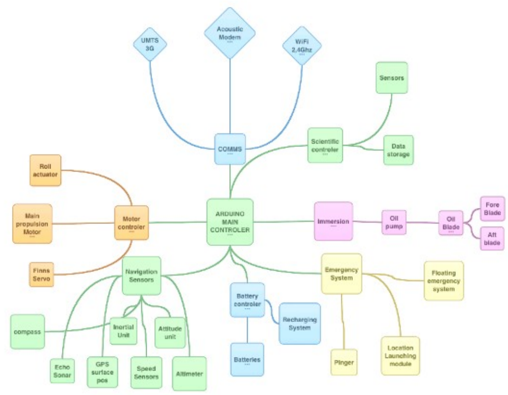


Fig. 10. Functional graphic of the operative modules and microprocessor

The vehicle propulsion is assigned to a standard commercial electrical outboard engine, and will test for the Mar Menor area for the maximum of 10 meters. The propeller sealing rings will be tested and reinforced if needed. Additional protection for deeper operation is under development in order to avoid water leakages inside the electric part of the motor and actuators.

TABLE I. RESULTS OF POWER REQUIREMENT IN BASIC FIXED POINT THRUST PROPELLER TEST

MOTOR PW Switch pos	Fixed point propeller test Power
1	6.00 Amp
2	7.40 Amp
3	12.9 Amp

B. PROPULSION POWER REQUIREMENT AND FIRST TEST

First tests of motor power consumption have been carried out in order get information regarding the maximum autonomy that can be expected. Due to the possibility of increasing the number of batteries by extending the middle section, the maximum range can be adjusted according to the characteristic of the mission. The motor is an electric brushed engine, with 45 Lbs of maximum thrust. Because of the drag force will be tested after the vehicle model will be assembled, at the speed of operation of 3 knots the maximum expected drag can be calculated.

The power will be adjusted according to this requirement and also the power required for maintaining this speed. The fixed point thrust propeller test provides a good approach to define the upper line in the propeller engine efficiency curve and establishes the maximum power requirement for each power control switch position.

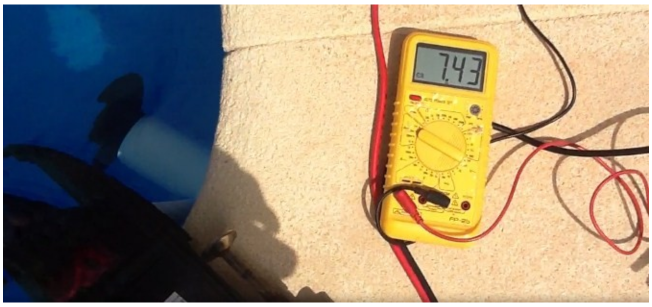


Fig. 11. Fixed point propeller test and measure of power requirements

Initial tests carried out in a swimming pool demonstrated a motor current need of 6.1 Amp at minimum speed and 7.4 Amp at second throttle position.

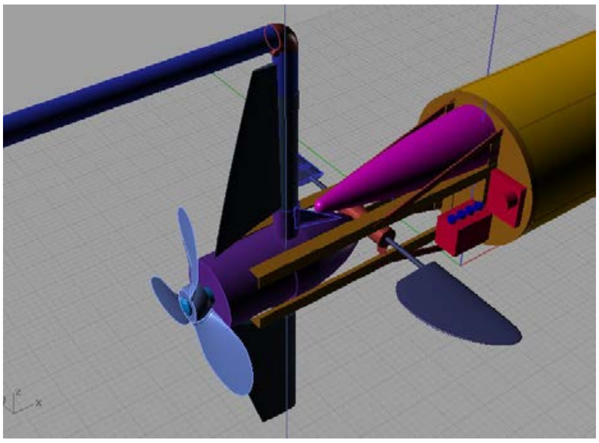
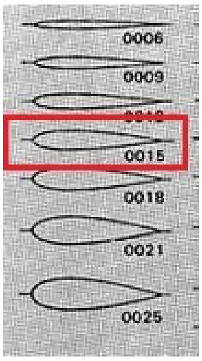


Fig. 12. Aft section detail showing foils actuators motor and Sampler and sensor

C. VEHICLE HIDRODYNAMIC ANALISYS

The following is an approximate analysis for evaluate the maximum range expected for the vehicle with mid section able for 5 batteries of 12Ah 12V as basic configuration.



Drag Coefficient

ALPHA	80000	160000	360000	700000	1000000	2000000	5000000	10000000
	REYNOLDS NUMBER							
0	0.0147	0.0116	0.0091	0.0077	0.0074	0.0070	0.0068	0.0068
1	0.0148	0.0117	0.0092	0.0078	0.0075	0.0071	0.0069	0.0068
2	0.0151	0.0120	0.0094	0.0080	0.0076	0.0072	0.0070	0.0069
3	0.0156	0.0124	0.0098	0.0083	0.0079	0.0075	0.0073	0.0071

Fig. 13. NACA 0015 foils main characteristics applied to the project

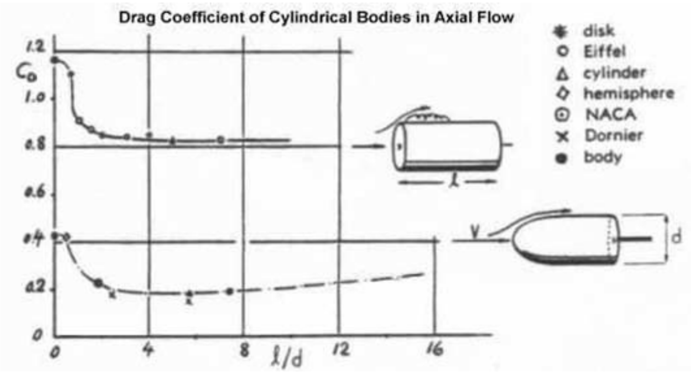


Fig. 14. Drag coefficient graph for applying to the AUV body

TABLE II. AREA IN CM^2 OF DIFFERENT COMPONENTS OF THE VEHICLE AND ITS PONDERED DRAG COEFFICIENT

Element	Area	Cant		Cd	Percentag	Result
Tail H Plains	19.6	2	39.2	0.007	0.0550	0.0004
Lower rudder	31.3	1	31.3	0.007	0.0439	0.0003
Short Mast and Antennas	172.0	1	172.0	0.600	0.2413	0.1448
Body	490.0	1	490.0	0.200	0.6873	0.1375
total			712.9	Vehicle Total Drag coeficient		0.2829

TABLE III. TOTAL VEHICLE FRONTAL AREA CM^2

Dimension	length	area	count	Area
Cilindrical	110	8639	1	8639
Paraboloid	25	1350	2	2700
Tail foils		286	2	572
Rudder foil		966	2	1932
Mast and Aerials		820	1	820
cilin nose aft	25	1963	2	3926
		Total Area		18589

The Reynolds number for the condition of operation and vehicle dimension is

$$R_e = \frac{v\,l}{\nu}\ , \quad \nu = \frac{\rho}{\mu}$$

$$\nu = 1.479\ 10^{6}\ m^2/s$$
$$l = 2.05\ m$$
$$v = 3\,Knots = 1.54\,m/s$$

$$R_e = 1.805\ 10^{6}$$

Being this value far higher than the limit between laminar/turbulent flow, 2 10^5, the vehicle will clearly advance on turbulent flow conditions.

The drag due to the effect of frontal effective area can be obtained from [12]

$$R_f = \frac{1}{2} C_D\, S\, \rho\, v_a^2$$

From the table II the frontal area including all the elements calculated is 0.0713 m2. The component of the resistance due to the effect of flow opposition frontal area affected by the coefficient C_D, which is pondered by the different element shapes drag particular coefficient [11], is

$$R_f = \frac{1}{2} 0.2829 \cdot 0.0713 \cdot 1{,}040 \cdot 1.54^2 = 24.875\ N$$

An additional component for the advance resistance can be assimilated to the frictional resistance of an area equivalent plate surface advancing at the same speed [6]. In this case we can apply the expression of the empiric ITTC-57 expression for frictional advance resistance in turbulent flow [11].

$$C_p = \frac{0.075}{(\log(R_e) - 2)^2}$$

Calculating using the value of Reynolds number the result of the coefficient is

$$C_p = 4.638 \cdot 10^{-3}$$

Replacing now on the Resistance due to total wet surface expression

$$R_p = \frac{1}{2} 4.638 \cdot 10^{-3} \cdot 1.8589 \cdot 1040 \cdot 1.54^2 = 10.632\ N$$

Adding both components of the advance resistance we can obtain the total resistance [6]

$$R_T = R_T + R_T = 24.875\ N + 10.632 = 35.507\ N$$
$$R_T = 35.5\ N$$
$$3.62\ Kg\ ,\ 7.9\ Lb$$

From the characteristics of the motor the maximum power is 500 w. The maximum thrust of the motor in these conditions is 45 Lb. Therefore, the thrust-power function is as shown in black line in Fig 15.

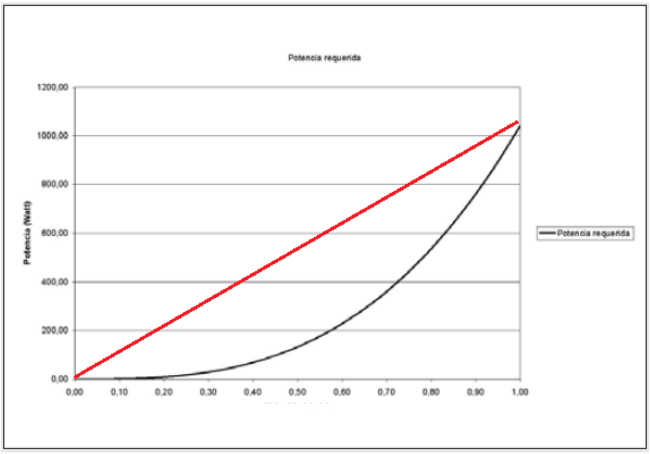


Fig. 15. Power-thrust function and linearization as upper limit

The relation between thrust and power is a cubic function. As we have not evaluate the propeller open water features we can consider as upper limit the linearization of the previous relation, drawing the shown red line on the graph . Using this linearization, the results obtained will be a conservative evaluation of the expected features in relation with the true expected features. This approximate relation will be useful before real tests will be conducted, then…

$$Rel_t = \frac{T_r}{T_M} = \frac{7.9}{45} = 0.175$$

Applying to the motor maximum power

$$P_R = 0.175 \cdot 500 = 87.5\ W$$

and then

$$\frac{87.5\ w}{12\ v} = 7.29\ A$$

As a result, the theoretical autonomy and range using 12Ah capacity 12 volts lead-gel standard batteries will be

$$\frac{12\ Ah}{7.29\ A} = 1.64\ h.$$

In order to avoid the total discharge of the batteries during operation and for avoiding unrecoverable damage on the accumulators, it has been considered the 60% of the total available energy as usable. Applying this percentage to the previously calculated results, the expected autonomy for a set of 5 batteries can be obtained

$$5 \cdot 1.64\ h \cdot 0.60 = 4.92\ h$$

In these conditions the maximum time of operation available for 5 x 12 Ah 12 volts batteries is expected to be 5 hours of continuous navigation, or the equivalent in distance 27.7 Km.

Total time of operation ;	**5 hours**
Total range:	**27.7 Km**

It is important to note that previous result are for applying to the vehicle short mast configuration, and are expected to by lower due to the added drag resistance in the case of long mast configuration.

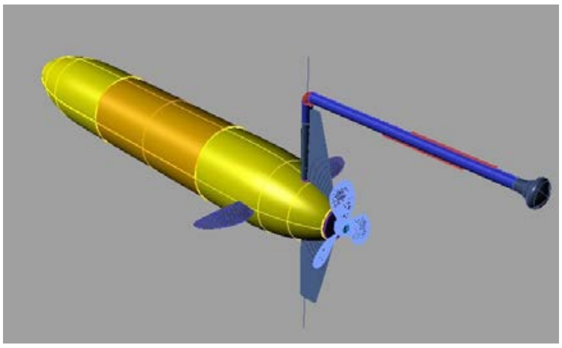


Fig. 16. Long mast replied in navigation mode

Consequently, the power will be adjusted according to this requirement and also the power required for maintaining this speed. The fixed point thrust propeller test provides a good approach to define the upper line in the propeller engine efficiency curve and establishes the maximum power requirement for every power control switch position.

Initial tests carried out in a swimming pool demonstrated the motor consumption of 6.1 Amp at minimum speed and 7.4 Amp at second throttle position.

D. FUNCTIONAL SCHEMA

The general functional schema shown in the fig 10 represents the functional modules initially considered in the vehicle. All the peripheral functions are centralized in the Arduino mega main controller. Peripheral sub controllers have been considered for distributed processing reasons, and a fail tolerant system is being implemented in order to guarantee the minimum operation and/or recovering procedures in the event of main controller failure.

E. PRESSURE HULL

The pressure vessel is configured in a base of a 2 mm INOX plate. This configuration will provide enough resistance for low and medium depth operation. The main goal is to provide enough flexibility to the vehicle in order to adapt its internal structure by changing the internal configuration depending on the mission requirements. Thus, the basic configuration is based on a single tube and is suitable for low depth operation areas like the ones that can be found in the Mar Menor, where the maximum depth is around 7,5 meters, being the average is 4,5 meters depth.

Because of the features mentioned above the basic configuration doesn´t require a very strong watertight hull structure more than the basic tube mentioned above. The possibility of including a set of internal structural elements depending on the operational average depth survey will provide an additional flexibility by adapting the vehicle to the special characteristics on the research area.

In case of fixed fins configuration for very deep operation, or in case of failure of the actuators, it is interesting to note that roll and pitch effect could be obtained by using a special system for moving the battery pack inside the watertight section. The pitch attitude will be adjusted by moving the battery pack forward and backward.

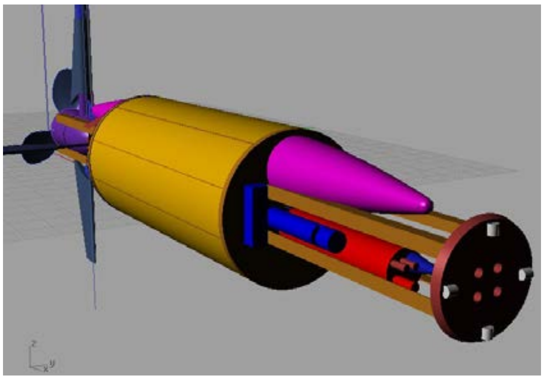


Fig. 17. Aspect of the nose section showing the bladder floating device and scientific instruments

A variable floating system as additional system of buoyancy control is considered. This system will operate by using two oil inflatable bladders one in the front section, the other one in the back section.

IV. COMMUNICATIONS

Communications is an essential element for the reliability of multivehicle operations. It is important to consider multiple ways data transmission both: between vehicles and shore base; and among all vehicles involved in the experiment. It has been considered on this project the duplicity on wireless communications using UMTS 3G UMTS and 802.11 WIFI, systems. IRIDIUM satellite communications has not been considered mainly for avoiding it related high cost of operation. The implemented communication system will provide a redundant capacity especially suitable for vehicles in inter-collaboration when they are in fleet operation mode.

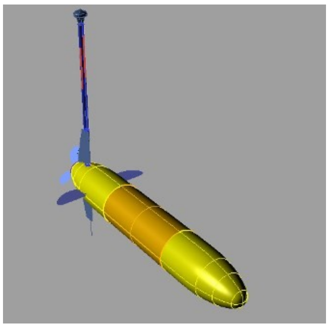


Fig. 18. Long mast extended for improving communications signal efficiency

The fact of be able of sending scientific data and navigation information to the command centre, possibilities the human intervention allowing of taking decisions in near real time. Human intervention during the evolution of an experiment [5] requires an accurate way for receiving information and for sending new instructions. Having the possibility of rearranging the mission according to a new observed situation provides an exceptional tool for adapting the vehicle operations to the real status on the experiment field without interruption . This vehicle has been designed considering the need of having permanent wireless link for getting scientific/navigation data and sending operative instructions.

Fig. 19. Basic electronic modules placed on watertight internal structure

The previously mentioned communication modules have two external watertight antenna located on the top of the mast. The external aerial set for communications is complemented with a GPS antenna. A protected releasable box for an autonomous GPS Tracker will be installed in this area too. This GPS tracker is capable of sending a configurable message via SMS when the vehicle is on the surface. As an additional functionality of this device, the GPS tracker watertight container will be automatically released in case of emergency, or even if time of vehicle operation exceeds a pre-established value. The GPS tracker signal emitted when the module reach the sea surface includes standard GPS position data. This data will provide very valuable information about the expected location of the vehicle in case of loss of contact.

Fig. 20. GPS UMTS tracker with 48 hours of autonomy

A. COMMUNICATION COVERAGE TESTS

Several tests were conducted in order to verify the capabilities of WiFi communications in the Mar Menor area. A surface small boat (kajack) was equipped with an autonomous WIFI communication system. This equipment consist in an USB standard commercial 802.11 unit installed on the top of a 1.2 m long mast and plugged to a netbook computer on the boat. A transmission station based on a desktop PC was placed in shore. This computer was equipped with a 6 dB DLink directional antenna and worked as WiFi signal transmitter. The results of measuring the sending/reception power and signal level indicated that this standard device was not powerful enough. As this situation could affect in an important way to the efficiency of the communications a more efficient antenna will be considered to be installed on the vehicle. Some tests are being carried out in order to validate this new device. As it has been observed during the previously mentioned tests, high frequency waves have affected in an important way to the WiFi communications. The wave spectrum usually found in the Mar Menor area promoted high frequency roll and pith movements on semi floating devices. These movements conditioned in an important manner the quality of communications. In order to avoid or minimize this interaction between the sea surface and the vehicle, a 1.5 m long mast has been considered. This mast will allow the vehicle to remain down the sea surface during communications process and thus, improve the communications signal quality.

Fig. 21. GPS UMTS tracker and WiFi test carried out during this year in the mar Menor area and inner islands.

V. CONCLUSIONS

Although in an initial stage of development, the interest of having a low cost underwater vehicle can complement the fleet for carrying out scientific surveys. The collection of oceanographic information and accurate environment data has been proven as extremely useful for understanding the ocean processes that affect the life on earth. The objective of designing and developing an inexpensive robust AUV, flexible, adaptive and economically feasible has been done. The possibility of applying this vehicle for massive oceanographic research is an interesting option when very advanced AUV features are not required.

The fact of having a vehicle based on commercial not expensive modules increases the feasibility of conducting long term surveys. The possibility of having a fleet of vehicles with the equivalent cost of only one commercial standard vehicle allows the possibility of operating in multi vehicular collaborative configurations. Although the capabilities and features of the proposed design are obviously lower in some aspects than other commercial AUVs, the fact of its low cost provides an additional and important advantage when no extreme conditions of operation or high complexity of the mission are required. The fact of using open source hardware and software provides an excellent test-bed platform able to be expanded with future developments.

Finally, this vehicle will be an excellent demonstrative equipment available for academic purposes and as test bed for future student projects of oceanic engineering, computing engineering, oceanographic science and other related areas.

VI. FUTURE WORK

Future works are expected to be carried out in order to finalize the first prototype at the end of this year, and thus be able to prove the vehicle capabilities. The development of any of the modules will require an additional effort that will need the collaboration of the authors and new students as well as professors. It is important to remark that the main aim of the project is to provide the possibility for involvement and motivation of students, researchers, and the academic institutions in this area of engineering and knowledge. The development of future student projects based on this vehicle will count with the possibility of conduct real test on it. This possibility should encourage new students and mentor to participate on the evolution of this vehicle. The development and construction of an autonomous recharging station adaptable to the AUV object of this paper will be considered in the next stage of this project..

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