AN AUTONOMOUS VEHICLE DEVELOPMENT FOR SUBMARINE OBSERVATION

Engineering

ABSTRACT

This work proposes the development of a low-cost ocean observation vehicle. This vehicle, a hybrid between Autonomous Underwater Vehicles (AUV) and Autonomous Surface Vehicles (ASV) moves on the surface of the sea and makes vertical immersions to obtain profiles of a water column according to a pre-established plan. Its design means production costs are low and efficiency is increased. Also, the vehicle is able to make high resolution space and time measurements simultaneously. GPS navigation allows the platform to move along the surface of the water while a radio-modem provides direct communication links and telemetry. The vehicle measures 1885mm by 320mm wide. It weighs 76kg. It navigates at a speed of 1.5m/s at 80% at full propulsion power and reaches a maximum depth of 20m. It is a vehicle of electrical propulsion with an autonomy of 3-5 hours. This work outlines the mechanical and electronic design of the vehicle, as well as considerations for navigational and immersion experiments.

***Key words* -** Autonomous Underwater Vehicle, vertical profiler, computer embedded.

INTRODUCTION

Despite major advances in ocean research by oceanographic ships and anchorages, tests on the marine environment are still insufficient. The limitations of conventional oceanic observation platforms cannot carry out tests in the sea and provide the required space and time measurements. For this reason and with the aid of recent technological advances, the development of new oceanographic observation platforms which are able to carry out high-resolution space and time interdisciplinary measurements simultaneously, have been tested. Observation platforms referred to as Gliders, Autonomous Underwater Vehicles (AUVs) and Autonomous Surface Vehicles (ASVs) have already been designed (Meyrowitz et al, 1996) (Blidberg, D.R, 2001). This project proposes the development of a low-cost oceanic observation vehicle which is a hybrid between the AUVs and ASVs. The vehicle moves along the surface of the sea and makes vertical immersions to obtain vertical profiles of a water column in agreement with a pre-established plan (Dabholkar et al, 2007) (Byron et al, 2007). These two characteristics of the observation platform lower the production costs and increase its efficiency. GPS navigation will allow the platform to move along the surface of the water while a radio-modem will provide direct communication links and telemetry.

MECHANICAL DESIGN OF THE VEHICLE

The design proposed here is a prototype which will have to be modified. The platform design is made up of a support structure on which the steering and propulsion mechanisms are attached. This structure is not watertight, thus allowing us to drill holes wherever required.

A watertight cylindrical module is located inside the support structure. It houses the immersion actuator and the electronics control, as well as the power supply provided by the batteries (Egeskov, 1994).

Support Structure.

As figure 1 shows, the support structure is made up of a PVC cylinder, 1.2m in length by 32cm in outer diameter. The simple construction means it is easy to make modifications. The final result is a platform which can house the bulky elements of the vehicle such as the batteries and the immersion actuator in the minimum space possible. The main Seaeye(™) propulsion engine is located at one the end of the support structure(Seaye). This engine, without brushes, runs on a supply voltage of 24V DC and nominal current of 5A, which provides a maximum thrusting of 110N to 950rpm (Dewijs, 2000).

Individual Seabotix(™) engines are located on the sides of the cylinder. These engines have a maximum thrust of 25N at a maximum power of 80W and are powered with 24V DC (Seabotix). When these engines are used, the course of the vehicle can be altered. This solution was favoured instead of a rudder system with a hydraulic cylinder because its construction is simple. (Desset et al, 2005). The engines, located on the sides of the device are attached to the support structure by means of a stainless steel telescope tube that allows the spindle, located on both of the vehicle's engines, to be altered during testing.

The main engine is attached to the support structure by means of a stainless steel tube and mechanized nylon blocks provide adequate rigidity.

Finally, depth and direction auto-stabilizers are located on the stern once again to ensure stability.

The bow is finished with a carbon fibre hemisphere.

***Watertight Module*.**

As figure 1 shows, the watertight module contains the set of immersion equipment, the electronic signal reception modules and engine control, and the power supply batteries.
All these parts are joined to the watertight PVC cylinder by means of a metallic structure. See below.
The watertight module is covered in black nylon. An o-ring and 12 M6 screws guarantee watertightness.

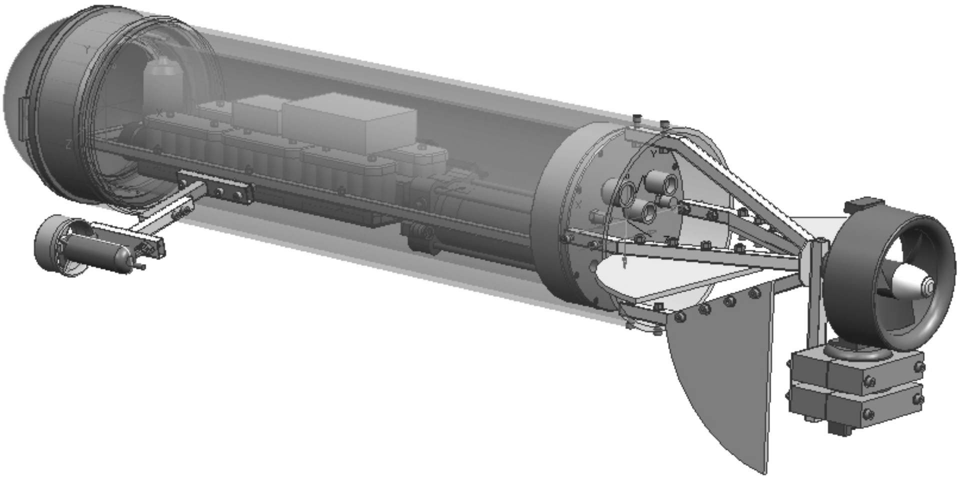


Figure 1. Frame

The design of the emersion and immersion equipment is composed of a commercial pneumatic stainless steel cylinder with a displacement of 1500cm3 and a linear electrical actuator which can cover a maximum distance of 200mm and a thrust force of 3KN. See figure 2.

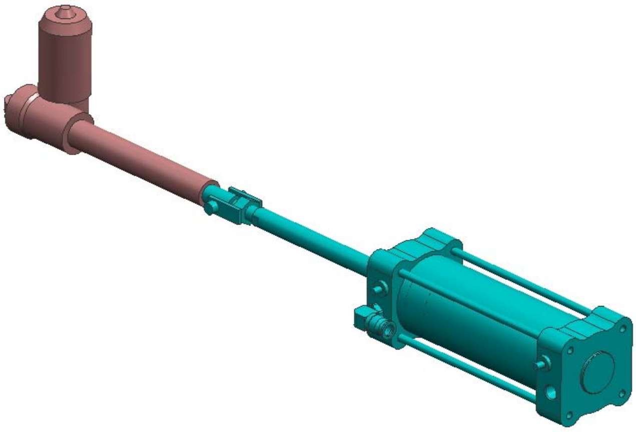


Figure 2. Emersion and immersion actuator

Complete structure of the vehicle.

Figure 3 and figure 4 show the external structure and watertight module of the constructed vehicle, respectively.

It is worth highlighting, that the position of the center of gravity ensures stability in immersion/emersion operations.

The payload works out at 5kg, approximately, on a gross weight of the 76kg platform.

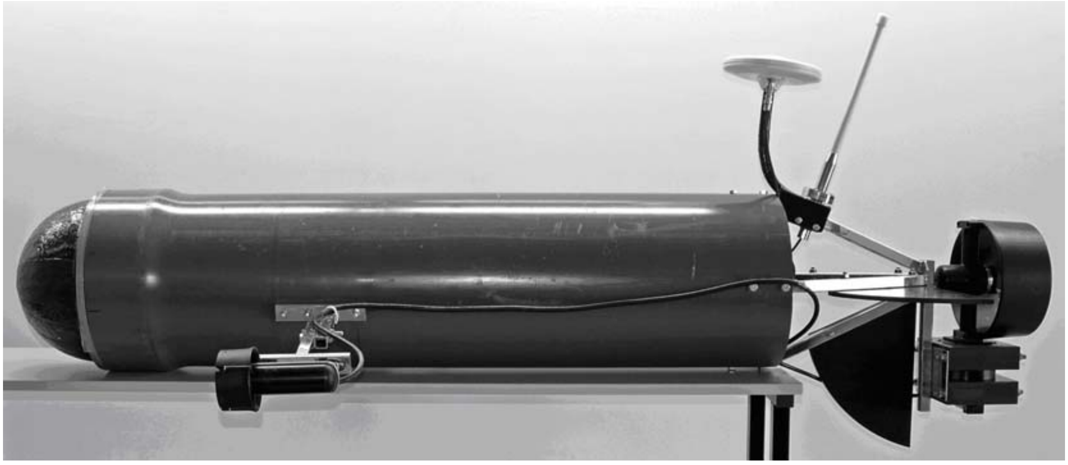


Figure 3. Constructed vehicle.

Figure 4. Constructed watertight module

ELECTRONIC DESIGN. CONTROL PHASE

The autonomous navigation control system is made up of an embedded computer and the elements necessary for communication, navigation and propulsion and data acquisition. Safety elements are also included (Desa et al, 2007). In figure 5 the diagram for the autonomous control of the vehicle is described.

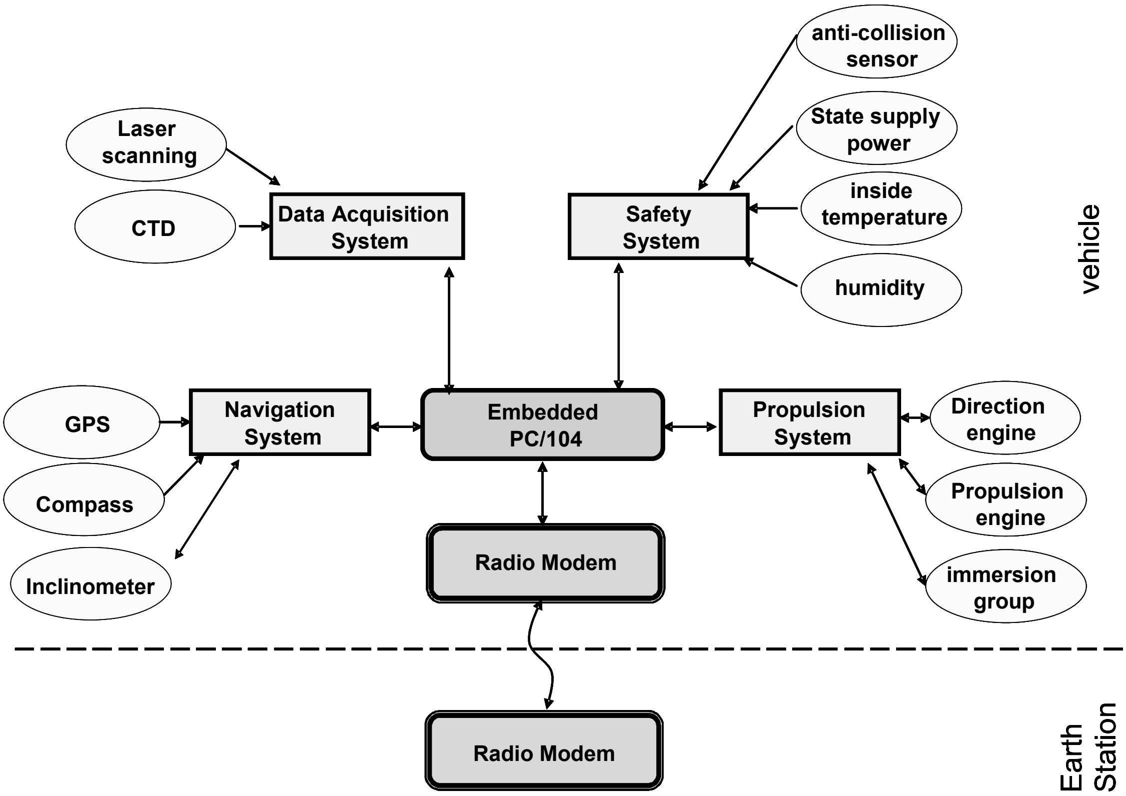


Figure 5. Diagram of the autonomous control system

Communication between the vehicle and the station located on shore is bidirectional and a Farell Instruments$^{(™)}$ industrial modem T-MODC48 has been used. See figure 6. Its features include a data rate of 4800 bps, protocol-transparent and a configurable carrier power of 100mW/5W that allows a maximum range of 10km and +/- 1 ppm stability level from -30ºC to 60ºC.(Farell)

Figura 6. Radio módem T-MODC48.

A PC/104 embedded computer (PM-6100 AEWIN) makes up the central control of the vehicle, see figure 7. It has an embedded AMD® Geode™ LX800 CPU up to 500MHz. This is of limited size, weight and power consumption (max 12W). It also has a low heat loss (Aewin). It is managed by a Windows XP operating system stored in a compact flash memory which provides good protection from vibration.

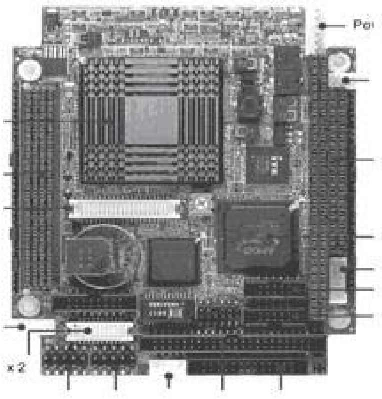


Figure 7. PC/104+ PM-6100

The propulsion control system is a SSC32 Lynxmotion driver. See figure 8. This transforms the RS232 signal from the PC/104 in a modulated PWM signal that acts on the engine power drivers. This servo-controller has 32 channels with 1uS-0.09º resolution and 1uS/Second speed. This can work at a velocity of 2400, 9600, 38.4k, 115.2k bauds. (Lynxmotion)

Several power drivers have been developed to adapt the modulated PWM signal received from the SSC32 so that the vehicle's engines can execute the control orders.

- *Power steering driver.* The steering orders received are transferred to individual adjustable-speed drives that control the engines responsible for moving to the left and right. These adjustable-speed drives incorporate the power electronics necessary to adapt to the engines changing requirements.

- *Power driver of immersion/emersion.* The immersion/emersion orders are applied to a control circuit that acts on the engine-cylinder equipment.

  This control circuit incorporates a microcontroller PIC 16F88 that interprets the signal received and consequently executes the stop/immersion/emersion orders on the electrical engine of the immersion/emersion equipment.

  The pneumatic cylinder incorporates individual magnetic limit switches which can block the electric engine's actuators and also act as a security system limiting the total displacement of the cylinder.

- *Power driver for propulsion.* The propulsion orders are processed on a microcontroller PIC16F873, which provides the control signal via RS485 to the propulsion engine. This engine includes the control and power electronics necessary to decode the orders received via RS485.

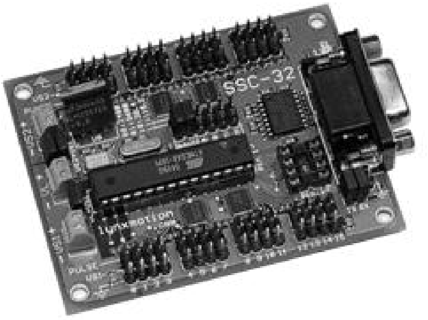


Figure 8. Controlled SSC32

The navigation system is a digital compass and a three-axis inclinometer, PNI TCM-2.6, see figure 9a. The TCM 2.6 is a 3-axis tilt-compensated compass-heading (also known as azimuth, yaw, or bearing angle) module with electronic gimballing to provide accurate heading, pitch, and roll measurements over a ±80° tilt range. This high-precision (heading accuracy 0.8°), high-resolution (Compass heading 0.1°) navigation system runs on low power (< 20 mA typical draw). (PNI)

The navigation system also has a global positioning system GPS, Magellan DG14$^{\text{TM}}$, which provides the precise location of the vehicle during a mission, see figure 9b.

The DG14™ is a sub-meter GPS+Beacon+SBAS receiver. It incorporates signals from Satellite Based Augmentation Systems (SBAS), such as WAAS, EGNOS & MSAS, or an embedded beacon receiver, to provide sub-meters differential positioning. DG14 can emit SBAS ranging, ephemeris and differential corrections through the serial port. Although DG14 offers three standard RS232 ports, it is also capable of single port operation.

It can provide up to 20-Hz precise three-dimensional positions and raw data for real-time guidance and navigation (Magellan).

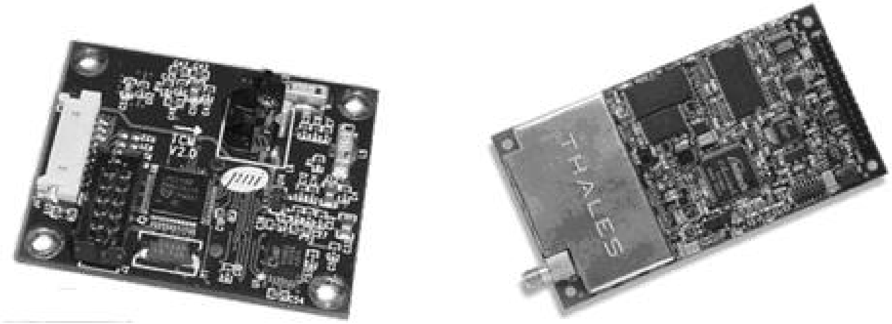


Figure 9. Navigation System. (a) PNI TCM-2.6 (b) DGPS, DG14

All this equipment is assembled inside two PVC boxes, as seen in Figure 10. One box houses the PC/104 with the navigation system and the other is equipped with the propulsion system. For both boxes a power bus which uses 24V, 12V and 5V has been installed. These voltages are generated from 6 Ni-Cd batteries, 24V nominal voltage and 21AH capacity, through a power stage implemented using switched dc-dc converters, located in a separate box.

Safety elements for the vehicle and a data acquisition system will be developed in the second stage of the project. Figure 10 shows the layout of all the elements in the watertight module.

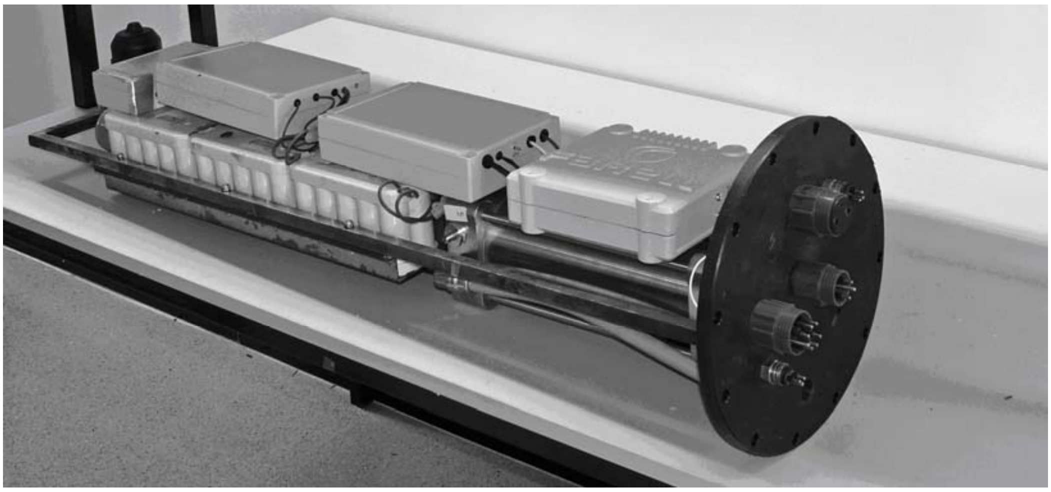


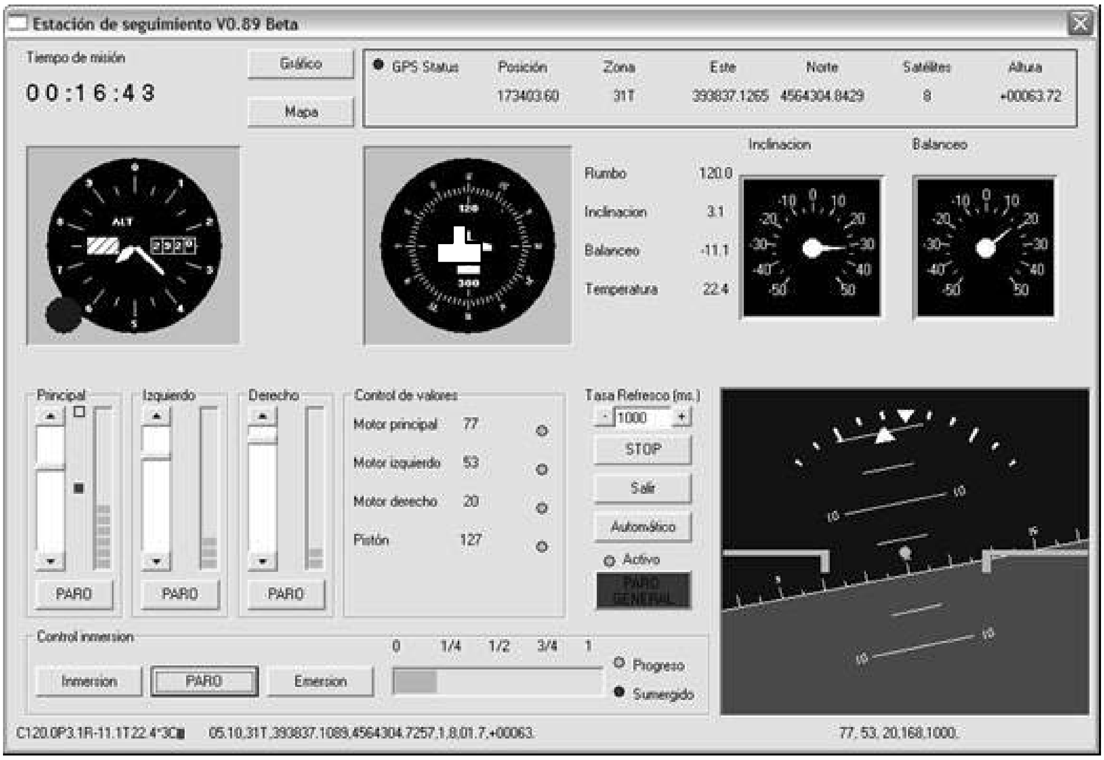
Figure 10. Inside layout of the watertight module

SOFTWARE DESIGN. TRACKING STATION

The vehicle needs user interaction in terms of control parameters, operational verification and data acquisition and downloading. A program has been designed which reads/writes the data received/sent by radio-modem, checks for transmission errors and represents the information graphically. Figure 11 shows the graphical user interface (GUI). The GUI has a two-page front-end. The main page incorporates direction, roll and pitch angles indicators and also an artificial horizon to view the data transmitted by the compass / inclinometer. This page also includes a series of Scrollbars and buttons to control the vehicle's engine. The second page presents the user with each of the parameters that the GPS receiver provides using TextBox and a variety of geo-maps to locate the position of the vehicle.

EXPERIMENTAL TESTS

When the vehicle was initially placed in the water, balance had to be adjusted. It was obtained by incorporating a 3.6kg ballast in the prow and a 1.5kg push in the stern. This was sufficient to allow the navigation and immersion tests to begin. In the navigation test the speed was approximately 1,5m/s with the control of the propulsion engine at 80% at full power. By using the lateral engines at full power and decreasing the propulsion of the first engine the trajectory, variation is obtained very easily. The immersion tests were carried out with complete normality acting on the engine-cylinder equipment.



Tiempo de misión
00:16:43

● GPS Status	Posición	Zona	Este	Norte	Satélites	Altura
	173403.60	31T	393837.1265	4564304.8429	8	+00063.72

Rumbo	120.0
Inclinacion	3.1
Balanceo	-11.1
Temperatura	22.4

Motor principal	77	○
Motor izquierdo	53	○
Motor derecho	20	○
Pistón	127	○

Tasa Refresco (ms.) 1000

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C120.0P3.1R-11.1T22.4*3C▮    05.10,31T,393837.1089,4564304.7257,1,8,01.7,+00063.                    77, 53, 20,168,1000.
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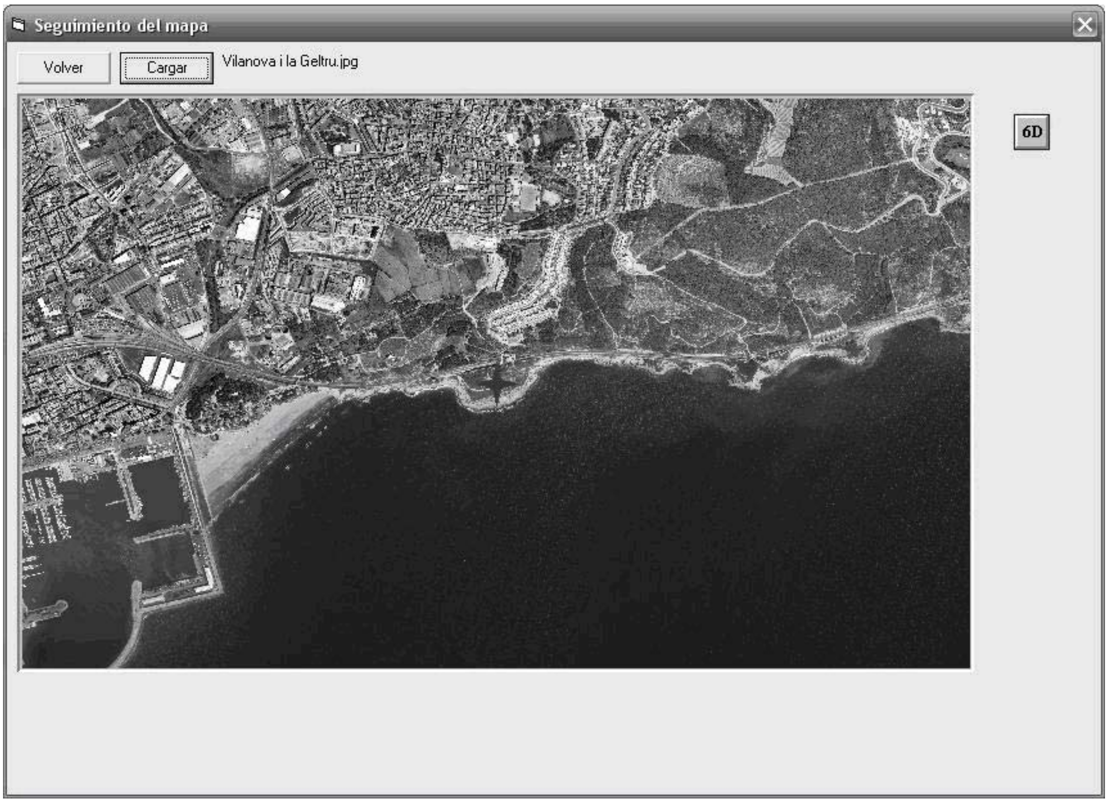
(a)



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(b)

Figure 11. Tracking Station (a) GUI Main Page (b) Geo-Map

CONCLUSIONS

The result so far is a robust platform which is relatively small and light, factors which facilitate its manageability and operability. To sum up we can say that a low-cost oceanic observation platform has been developed which is able to navigate on the surface of the sea and make vertical immersions to obtain water column profiles.

ACKNOWLEDGMENT

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APPENDIX

RESUMEN

En este proyecto se desarrolla un vehículo de observación oceánica de bajo coste, híbrido entre los *Autonomous Underwater Vehicles (AUV)* y los *Autonomous Surface Vehicles (ASV),* esto es, que se traslada por la superficie del mar y realiza inmersiones verticales para la obtención de perfiles de la columna de agua de acuerdo con un plan previamente establecido. Estas dos características de la plataforma de observación propuesta, abaratan los costes de producción e incrementarían su eficiencia. El desplazamiento superficial de la plataforma permite la navegación mediante GPS y la comunicación directa y telemetría mediante radiomódem. Las dimensiones del vehículo son 1885mm de longitud y 320 de diámetro exterior, y posee un peso de 76 kg. En las pruebas de navegación alcanzó una velocidad de 1.5m/s a un 80% de potencia de propulsión y una profundidad máxima de 20m. El vehículo posee una propulsión eléctrica con una autonomía de 3-5 horas.

DISEÑO MECÁNICO DEL VEHÍCULO

Teniendo en cuenta que el diseño actual corresponde a un primer prototipo sobre el que, necesariamente, deberán realizarse sucesivas modificaciones, se propone un diseño mecánico constituido por una estructura de soporte sobre la que se acoplarán los motores de dirección y propulsión. Esta estructura no es estanca, lo cual va a permitir realizar cualquier tipo de mecanizado. En el interior de la estructura de soporte se acopla un módulo cilíndrico estanco que contiene el actuador de inmersión y la electrónica de control, así como las baterías de alimentación.

Tal como muestra la figura 1, la estructura de soporte se compone de un cilindro de PVC de 1.2m de longitud y 32cm de diámetro exterior. En uno de los extremos de la estructura de soporte se acopla un motor principal de propulsión de la empresa Seaeye. Este es un motor sin escobillas con tensión de alimentación de 24V DC y corriente nominal de 5A. Proporciona un empuje máximo de 110N a 950rpm. En los laterales del cilindro se acoplan sendos motores de la empresa Seabotix con un empuje máximo de 25N a una potencia máxima de 80W alimentados también a 24V DC. Dichos motores permiten modificar la dirección de navegación.

Tal como muestra la figura 1, el módulo estanco contiene el grupo de inmersión y emersión, que se ha diseñado a partir de un cilindro neumático comercial de acero inoxidable con desplazamiento de 1500 cm3 y un actuador eléctrico lineal con una carrera de 200 mm y un empuje de 3KN de fuerza, alimentado a 24V. Ver figura 2.

En las figuras 3 y 4 se puede observar el vehículo construido.

DISEÑO ELECTRÓNICO. FASE DE CONTROL

Se ha diseñado y desarrollado un sistema de control, basado en un ordenador embebido PC/104+ PM-6100 de AEWIN, que permite una navegación autónoma del vehículo. En la figura 5 se describe el diagrama de bloques del control autónomo.

La comunicación entre el vehículo y la estación terrestre es bidireccional y se ha realizado a través de un radio módem industrial T-MOD400 de la empresa Farell Instruments. La figura 6 muestra una imagen del equipo que posee una velocidad de transmisión de datos 4.800bps, una potencia configurable de 5 W que permite un largo alcance (10Km) y una estabilidad +/- 1 ppm desde -30ºC a +60ºC.

El control central del vehículo se ha encargado a un ordenador embebido PC/104+ PM-6100 de AEWIN, cuyas dimensiones y consumo son reducidos. Además, posee una baja disipación de calor que favorece su ubicación en el interior del módulo estanco. Está gestionado por un sistema operativo Windows XP almacenado en una memoria compact Flash, que proporciona mayor fiabilidad frente a vibraciones que un disco duro. La figura 7 proporciona una imagen del equipo.

El sistema de de control de la propulsión lo constituye un controlador SSCC32 de Lynxmotion que transforma la señal RS232 procedente del PC/104 en una señal modulada PWM que actúa sobre la etapa de potencia de los motores. Este controlador posee 32 canales con salida desde 0,50ms hasta 2,50ms y con una resolución de 1uS. Puede trabajar a velocidades 2400, 9600, 38400 y 115200 baudios. En la figura 11 se puede observar el controlador de servos. Para la etapa de potencia se han desarrollado diversos circuitos que permiten a los motores ejecutar las órdenes recibidas.

El sistema de navegación lo constituye un compás digital con un inclinómetro de tres ejes, PNI TCM-2.6, que proporciona el rumbo y los ángulos de cabeceo, guiñada y avance (ver figura 9). El rango de inclinación es de ±80º con una precisión de 0.8º y una resolución 0.1º. También se ha incluido un sistema de posicionamiento global GPS, DG14 de Magellan, (ver figura 9), que proporciona una ubicación precisa del vehículo durante la misión.

Todos estos equipos se han montado en el interior de dos cajas de PVC, tal como se dispone en la figura 10. Por ambas cajas circula un bus de alimentación con 24V, 12V y 5 V. Estas tensiones se generan desde las baterías de Ni-Cd, de tensión nominal 24V y 21AH de capacidad, mediante una etapa de potencia implementada mediante conversores conmutados dc-dc, ubicados en una caja independiente.

DISEÑO SOFTWARE. ESTACIÓN DE SEGUIMIENTO

Para disponer de una buena operatividad con el vehículo se ha creado un software que permite leer/enviar datos por el radio-modem, gestionar los eventuales errores de transmisión y presentar gráficamente estos datos. Se incorpora la posibilidad de realizar un control manual del vehículo desde la estación de seguimiento.

RESULTADOS EXPERIMENTALES.

La primera vez que se introdujo el vehículo en el agua se procedió a ajustar su perfecto equilibrado. Se consiguió incorporando un lastre en proa de 3.6kg y un empuje en popa de 1.5kg. Esta situación permitió el inicio de las pruebas de navegación, de direccionamiento y de inmersión.

En la prueba de navegación se obtuvo una velocidad aproximada de 1,5m/s con el control del motor de propulsión al 80%. La variación de rumbo se consigue con gran facilidad utilizando los motores laterales a plena potencia y decrementando la potencia del motor de propulsión. La operación de inmersión/emersión se realizó con toda normalidad actuando sobre el grupo motor-cilindro.

CONCLUSIONES.

Como resultado, actualmente, se dispone de un vehículo de unas dimensiones y peso no excesivo que permiten una buena maniobrabilidad y operatividad. Como valoración final se puede decir que se ha desarrollado un vehículo para la observación oceánica de bajo coste que permite navegar por la superficie del mar y realizar inmersiones verticales con el objetivo de obtener datos de una columna de agua.