ROBOSUB
Isaac Peral y Caballero

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“Isaac Peral y Caballero”
Autonomous Underwater Vehicle

Team
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Abstract
Unmanned Vehicles are no longer science fiction. Their potential grows exponentially, the same way as their market, and events like the Fukushima disaster in Japan probe the present necessity of these vehicles.
The RoboSub “Isaac Peral y Caballero” is an AUV(Autonomous Underwater Vehicle) done and managed completely by students of several Spanish universities. This project aims students of different types of degrees(marketing, software engineering, naval engineering, etc.) to work together in order to be better professionals. Furthermore, it pretend to be a platform of innovation where students can apply their ideas in AUV(Autonomous Underwater Vehicles).
This Robot, one of the firsts of the European Union in participate in the RoboSub competition, has some keypoints in the design such as a pump-based propulsion, electronic devices designed and made by us and real-time software which uses JDErobot Software Development Suite.
However, this project is expected to continue thorough time integrating elements, which we were not capable to include them because of lack of time and resources, like passive sonar, active sonar, SLAM(Simultaneous Location and Mapping), etc. Lastly, our approach to the development of the “Isaac Peral y Caballero”AUV was not only technical. Communication also was a vital part in this project. That is

1/ Introduction

In Summer 2011, students of the Universidad Politécnica de Madrid and the Universidad Nacional de Educación a Distáncia of Spain found the AUVSI Foundation webpage. They immediately became encouraged by the idea of participating in the 15th RoboSub competition, which is organized by the own AUVSI(Association for Unmanned Vehicle Systems International) and ONR(Office of Naval Research of the U.S. Navy) in San Diego, California, from July 16th to 22th of 2012. It was not easy. It cost a lot of months to achieve the resources they needed in order to design and built a robosub but finally, in March 2012, the company SAES believed in the project and sponsored it. Thank to this sponsor and others, the students of FuVe could construct the "Isaac Peral y Caballero"AUV. This vehicle takes its name from the Spanish inventor of the torpedo submarine.

Isaac Peral and Caballero

2/ Mechanics

Speaking about the motion system of our submarine, we have chosen a non-conventional pump-based system. This choice is made because it allows for better maneuver control, reduced consumption and lower price (2:1) than a propeller-based system.

A- MECHANICS DESIGN IDEAS

Our AUV uses four centrifugal pumps operating permantly which are distributed horizontally in order to cancel the total torque.The usage of this type of pumps is due to the necessity of having high water flow with high speed and low pressure. High pressure flow would mean larger pumps (Fig-1.) and more pressure drop. Consequently, we would need more energy, more batteries, stronger structure, etc. . Hence the choice of these centrifugal pumps.

Fig-1. Pump

IIt is important to note that the pumps are integrated into the hull. This implies that the hull is partially flooded. This improves the buoyancy and stability of our robot. In order to not increase the wetted surface, however, we decided to cover our submarine and put the pumps inside of it.

This way, the own pumps absorb part of the friction and generate a false shield which makes the inertia lower.

B- MANEUVER SYSTEM

The maneuver system is a consequence of the type of propulsion and our desire of having a submarine with maximum possible mobility. Our AUV uses 18 valves to control the flow that comes from the pumps through the pipes. They are placed in extreme positions of the vehicle in order to generate enough torque to turn in all three dimensions.

This valve system allows us to maneuver at 4 or 5 different speeds. These speeds enable our vehicle to achieve very precise positions.

This total control of the course is possible because of the continuous operational regime of the pumps. This regime also reduces vibrations and noise that affect the data acquired systems, and the energy consumption due to the lack of turn on/off during the mission. Finally, we have chosen a butterfly valves which are actuated by waterproof servoes.

C- ESTRUCTURE

The hull is divided in three zones: prow, rear and center.

Rear and prow are fabricated by welded parts whereas the center is an union piece between rear and prow. We have used aluminum 6063 with termical treatmen T5 that allows us to weld it using TIG.

The aluminum 6063 (Fig-2.) offer us excelent quality in marine enviroment and high mechanical resistance. Another benefit of this material is the magnetig shield that protects our systems. The aluminum box in the middle contains all the computers and part of the electronic devices that our vehicle needs. The choice for this material was mostly due to the thermal conduction and the magnetic shield.

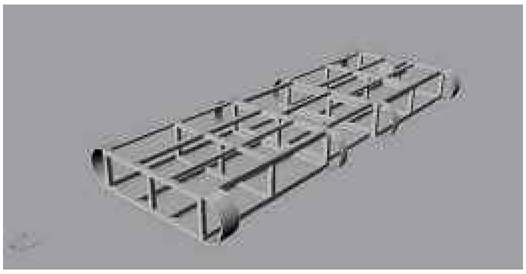

Fig-2. Structure

C- PIPES

In order to do guarantee the waterproof of the boxes and other systems, we have used propylene pipe (Fig-3.) with their accesories in order to comunicate the boxes with optic fiber and wires.

Fig-3. Pipes

2/ Electronics

The following is a list of the main electronic systems in our submarine. Due to serious budgetary problems funding arrived a bit late and some of the systems are not fully operational at the time of 2012 contest and backup systems were to be used instead.

A- CENTRAL CONTROL SYSTEM

The Central Control System will run the IA and the Mission Control System. It will include an x86 PicoBoard (very low power consumption) and ability to record all mission data.

B- SENSOR FUSION SYSTEMS

The Sensor Fusion System will process the information of all underwater sensors including Stereoscopic Vision System. Consist of an i3 Intel + CUDA pack. The system is able to record and reproduce the data throughout the mission in a SSD (Solid State Disk). It is connected to Sensors System via fibre-optic link.

C- CAMERAS VISION SYSTEM

Simple Vision System will process information from two high-definition CMOS cameras. Consist of a processor board based on an x86CPU + CUDA pack. There are two of such systems, one forward-looking and one downward-looking. The systems are autonomous and are connected by optical fiber to the Sensor Fusion System. Currently Computer Vision System, Central Control System and Sensor Fusion System are by optical fiber to the Sensor Fusion System. Currently Computer Vision System, Central Control System and Sensor Fusion System are operating on same board although Fibre-Optic Link is operational. All the vision system is soported by a lighting system LED (Fig-4.).

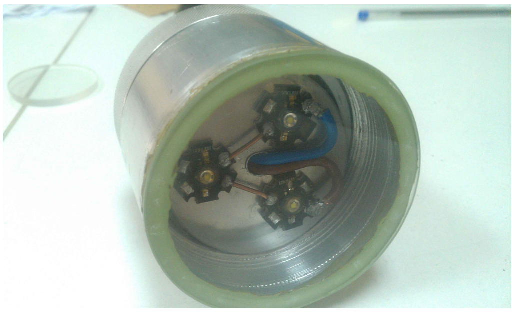

Fig-4. LEDs

D- INERTIAL NAVIGATION SYSTEM (INS)

The Inertial Navigation System (INS) consists of 3-axes accelerometers, 3-axes gyroscopes and 3-axes magnetometers controlled by a low-power digital signal processor (DSP). It provides real time information about position, course and pose/attitude of the submarine. The systems are autonomous and are connected by optical fiber to the Sensor Fusion System. Currently boards are not yet fully operational and calibration board is used instead.

E- ENERGY SYSTEM

The power of our AUV comes from LiFePO4 bateries because of their huge energy density. In fact, using this bateries, the autonomy of the submarine is one hour.

F- DEPTH GAUGE

Depth Meter (Fig-5.) consists of a pressure sensor and a low-power microcontroller apt for fresh and marine waters. It provides real time information on depth and temperature at which the submarine is. The system is autonomous and is connected by optical fiber to the Sensor Fusion System.

Fig-5. Depthmeter

G- GRASPING SYSTEM

The Grasping System consists of a series of electronic circuits and microcontrollers that are responsible for controlling two mechanical claws capable of holding an object by restricting its mobility by 3 degrees of freedom. The system is autonomous and is connected by optical fiber to the Sensor Fusion System. Electronics is operational but mechanical arrangement is not yet finished.

H- PROPULSION CONTROL SYSTEM

The Propulsion Control System consists of a series of power-electronics and microcontrollers(Fig-6.A and B) that determine and control the power of the motors, actuators and flow control valves. The system is autonomous and is connected by optical fiber to the Sensor Fusion System. This was the original design and part of it was actually built, although it was recently changed by a system to control servo-valves instead of solenoid-valves using standard PWM control.

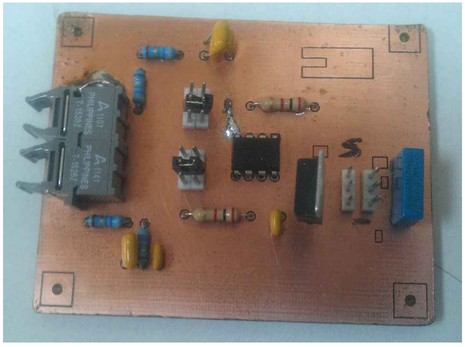

Fig-6 A. Fiber optic receiver

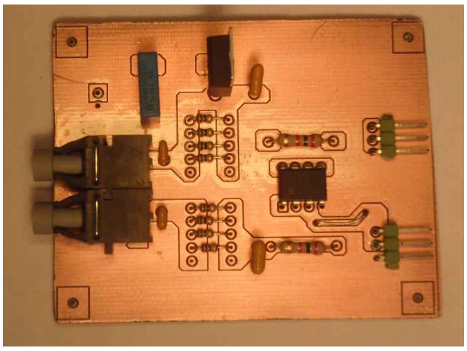

Fig-6 B. Fiber optic transmitter

I- SMART TORPEDO CONTROL SYSTEM

The Smart torpedo Control System consists of a series of electronic circuits and microcontrollers that are responsible for on the fly programming torpedoes with target coordinates, the best route to reach it and in turn releases it once it is confirmed that programming has been received and stored by the torpedo.

The two systems are autonomous and are connected by optical fiber to the Sensor Fusion System. Although PCBs and hull are done, firmware was not completed in time and had to be delayed for 2013.

The two Smart torpedoes encapsulate a series of electronic circuits, accelerometers, gyroscopes, magnetometers, FPGAs, DSPs and CMOS image sensors.

They are in charge of guiding the torpedo to the target coordinates following the best path (Fig-7.) that has been previously informed by the submarine.The torpedoes are autonomous and are connected by optical link to Smart torpedoes Control System.

J- START & KILL SWITCH SYSTEM

The Start & Kill Switch System consists of a simple ON/OFF switch that cuts-off main power supply to pumps, thus disabling propulsion as stated in RoboSub competition rules.

3/ Software

We have developed all of our software from ground up. We've focused mainly on three mayor aspects: modular infrastructure, computer vision robustness and finally real-time processing. The software is built upon the Ubuntu GNU/Linux operating system. All custom software is written in C/C++.

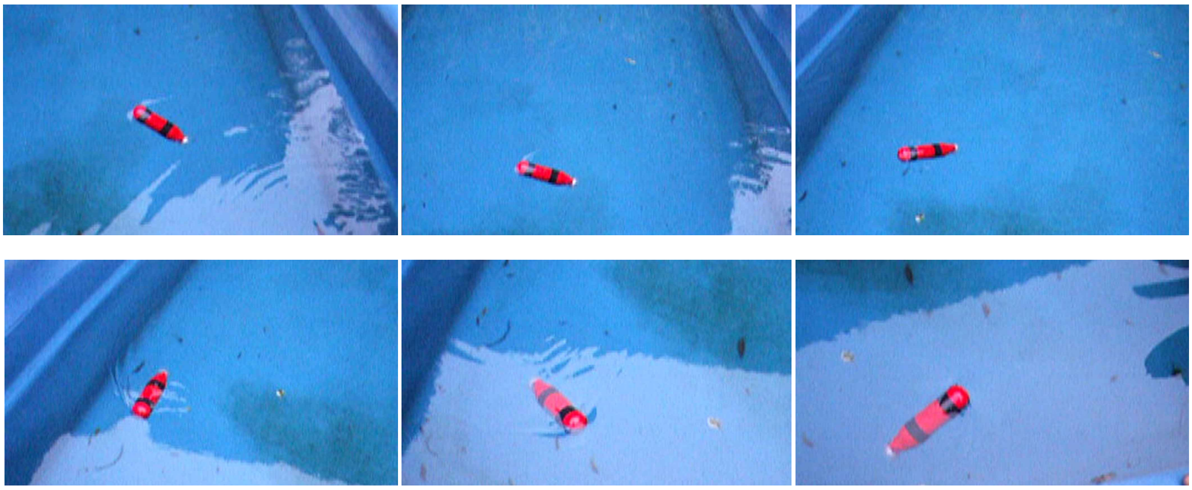

Fig-7. Gyratory movement of the torpedo, sequence.

A- ONBOARD COMPUTER

The software on the Isaac Peral y Caballero is powered by a mobile quad-core 2.40 GHz 6MB processor, along with a 2GB DDR3192-bit 43,2Gb/sec 144 CUDA cores graphic card, 8GB DDR3 1333 MHz SO-DIMM ram and a 60GB 6Gb/sec solid state drive (SSD). The overall system (Fig-8.) power consumption does not exceed 120 watts.

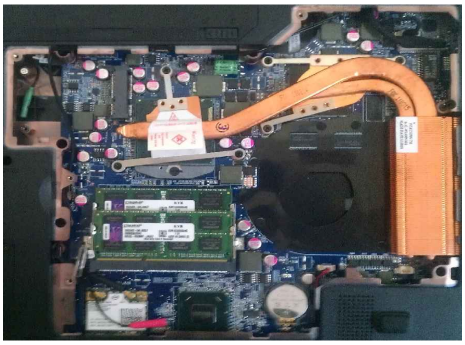

Fig-8.Onboard Computer

B- JDE ROBOT

JDErobot [1] is an open-source (GPL and LGPL) software development suite for robotics, home-automation and computer vision applications used in teaching and research. It is written in C language and provides a component-based programming environment where the application program is made up of a collection of several concurrent asynchronous threads called schemas. Each thread is dynamically loaded into the application. This framework uses these schemas as the building block of robot applications. They are combined in dynamic hierarchies to unfold behaviors. We've developed drivers to support the USB servo controllers, CMOS Image sensor boards, IMU and depth sensor (pressure sensor).

C- CONTROL SYSTEM

The control system for the Isaac Peral y Caballero combines a simple and effective finite state machine on top of classic Proportional Integral Derivative controllers. It has a multi-layered architecture, where top layers use feedback provided by lower layers, so the AUV can take decisions based on the environment.

D- VISION PROSSECING

In order to achieve a robust image (Fig-9.) processing algorithm, we need to make it chroma nondependent, and very lightweight in order to achieve real-time. Therefore we decided to avoid the usage

Fig-9 A. Input Image

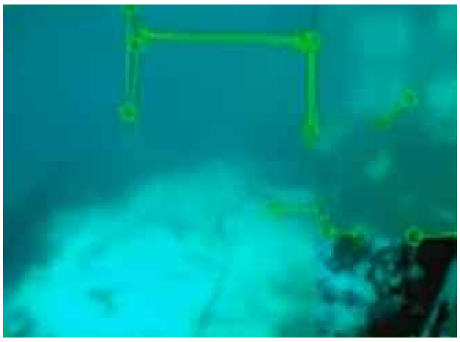

Fig-9 B. Output Image

Fig-9. LDC non segmented image

of Hough transform in favor of LDC [2], which stands for Line Detection algorithm using Contours.

In LDC (Fig-10.) we pre-process the input image with normalization, Gaussian smooth, Laplace edge detection and thresholding. These steps produce a binary image representing the borders from the image. We then extract the consecutive boundary pixels from each component that create the contours of the image. Contours are then divided into short segments, which are classified by their orientation, into 9 discrete categories. Finally, line segments are detected by finding consecutive sequences of segments of similar slope.

Fig-10 A.Input Image

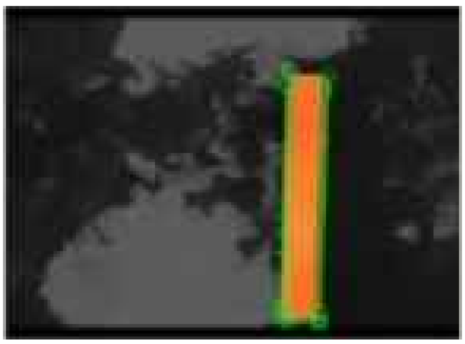

Fig-10 B.Output Image

Fig-10. LDC segmented image

LDC is somewhat faster than the Hough Transform algorithm. Extracting edges from input images takes similar time, but LDC is much more efficient in extracting line segments from edges than the Hough Transform solution. We further improved LDC by eliminating duplicated lines.

Later, the info provided by the LDC algorithm is combined with Kalman filters that allow an efficient estimation of the position of the detected lines even under conditions of occlusion. Thus, combining these results with simple color filters and feature detectors allows us to have a high level of certainty in the detection of objects.

E- MISSION PLANNER

The AUV has a component developed using JDErobot that allows us to plan each task down to the smallest detail. This component is called visualHFSM [3] (Fig-11.)and it permits us to visually delineate finite state machines, allowing us to describe the behavior of the vehicle with precision. VisualHFSM generates XML code that can be easily modified to archive missions which can later be retrieved and/or modified in the future

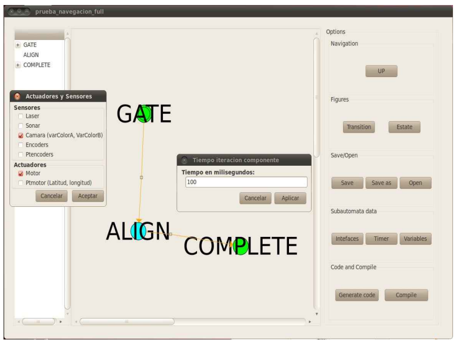

Fig-11. Visual HSFM

F- SIMULATION AND GUI

Before testing our algorithms in the AUV, we use Gazebo simulator to study the behavior of our submarine in a virtual world (Fig-12.). Gazebo is a multi-robot simulator for outdoor environments, capable of simulating a population of robots, sensors and objects in a three-dimensional world. It generates both realistic sensor feedback and physically plausible interactions between objects.

Although Gazebo is not originally designed for underwater environments, it provides valuable

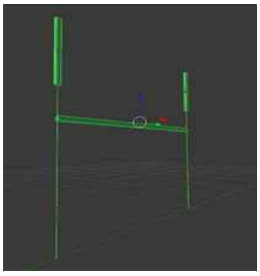

Fig-12 A.Gate

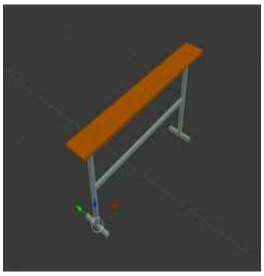

Fig-12 B. Path

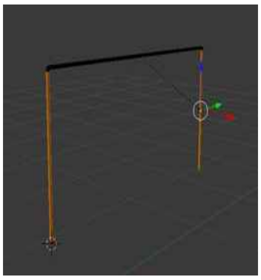

Fig-12 C. Obstacle course

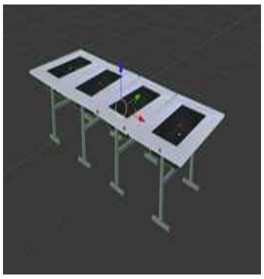

Fig-12 D.Gladiator ring

Fig-12. Blender 3D modeled tasks

information from the sensors, and allows us to make proofs of concepts from every algorithm implemented

Finally, the submarine has a semi-automatic mode (Fig-13.) where it is controlled by a driver, via a fiber optic link, converting it into an ROV (Remotely Operated Vehicle). It is then, through the use of a GUI, that the driver can control the submarine and visualize the status of the systems, the images from the cameras, and all the other sensors, making it possible to navigate in a controlled manner by means of a keyboard.

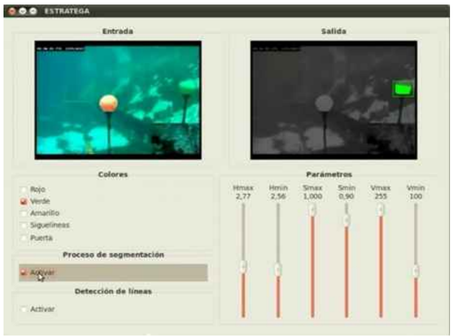

Fig-13. Stratega component

3.1/ REFERENCES

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5/ Acknowledgment

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