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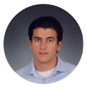

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ROAZ and ROAZ II Autonomous Surface Vehicle Design and Implementation

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***Abstract*- The design and implementation of the ROAZ and ROAZ II autonomous surface vehicles (ASV) is presented. These systems were developed at Autonomous Systems Lab, ISEP/IPP – Instituto Superior de Engenharia do Porto under a research program in marine robotics. With multiple applications either in river and estuarine environments or in the sea, the system applications in search and rescue operations are addressed and were taken in consideration for the overall system design.**

Mechanical design issues are discussed. Hardware, software and implementation status are described along with the control and navigation system architecture. The real time vision processing system is described and results are presented in operational scenario.

I. INTRODUCTION

Autonomous mobile systems have relevant applications in numerous fields of human activity. The areas of environmental monitoring and surveillance are an example of this.

Autonomous surface vehicles have been developed for science applications ranging from standard oceanographic ones [8] air-water microlayer studies [2], and also for AUV support either in navigation or providing communications surface relays [7], [10].

Advantages over the use of robotic systems come from the large environment areas to be covered, repetitive tasks and the usual benefices of autonomy by reducing the human factor (both by reducing associated costs and by improving quality of results).

The vehicles multiple sensor payload capabilities allow them (with particular emphasis on the sea ready ROAZ II) to be used in search and rescue operations. This can be done in two main roles, either in support activity such as maintaining communication links or providing additional sensory data or by direct intervention in active target search or recovery.

Although not specifically designed for search and rescue, the presented ASVs embody a set of technologies of relevance to search and rescue in marine environment.

The vehicles were developed under the research activity pursued on multiple autonomous robots, developed by the Autonomous Systems Laboratory at ISEP - Institute of Engineering of Porto.

In the following sections the vehicle design options and considerations are presented, followed by a brief description for the control and navigation system and ending with some preliminary results and final comments.

II. VEHICLE DESIGN

A. *Mechanical Considerations*

The ASV developments lead to the implementation of a smaller vehicle suitable for river and estuarine environments prior to the development of the ocean capable one. Since both vehicles share the fundamental autonomous control and navigation architectures, it is possible to develop and test first in a platform with reduced operational requirements (ROAZ) thus allowing the leverage of experience and validation for the implementation in the ROAZ II system.

A twin hull configuration was chosen for both vehicles in order to achieve good stability with low drag and provide easy water access for different systems to be mounted on-board (such as recovery mechanisms, deployable sensors or autonomous underwater vehicle docks).

ROAZ ASV was designed with reduced operational logistic requirements. These coupled with a typical river operation scenario imposed limits on the overall vehicle dimensions. It was developed in fibreglass structure reducing weight. The thrusters are externally stern mounted (Fig 1).

Figure 1. ISEP/IPP ROAZ Vehicle.

This configuration allows the ease of thruster exchange and good vehicle transport configuration.

The vehicle has relatively low area exposure above water with all the electronics in the bridge section between hulls, thus reducing wind effects. It has a flat top surface allowing solar panel coverage and an antenna bridge.

The central section has structural fixation points underneath and a connector's access for application of different types of sensors and mobile AUV dock mechanism.

A payload up to 50 kg can be added. Battery support and fixation is provided inside the hulls.

A bottom sealed hatch in the central section can be configured with different plugs and connectors according with the sensor suite used.

The vehicle overall dimensions are 1.5x1x0.52m, and the hulls were designed in order to reduce hydrodynamic drag.

The ROAZ II system followed a catamaran design and was developed in order to allow full open sea operations.

The two high density polyethylene (HDPE) hulls are connected by transversal aluminum tubes with a supporting stainless steel platform. The overall vehicle weight is around 200 kg and has 4.5 meters long for 2.2 meters width and 0.5 meters height.

Figure 2. ISEP/IPP ROAZ II Vehicle

The on-board computational system, embedded thruster control unit and several navigation sensor electronics are housed in one of two watertight boxes mounted on the central platform. The other houses four 12V AMG batteries providing 24V and 12V power capability. These boxes are implemented by two sturdy Peli cases assuring the necessary protection for sea operational missions. All subsystem connections are done through IP69 plugs thus ensuring weather and waterproof connection.

Two Minnkota trolling motors providing 22 kilograms of bollard pull each achieve vehicle propulsion.

On a raised bridge the vehicle as a WIFI 802.11 a/b/g antenna for communications, a 2.4Ghz wireless video link, GPS antenna and vision system.

The vision sensors are a day/night video camera and a thermographic infrared camera.

Attached to the central structure and deployed in the water the vehicle has a retractable sensor fixing mechanism allowing the use of underwater sensors such as a sidescan sonar or sonar altimeter.

B. *Propulsion*

A dedicated thruster was developed for the ROAZ vehicle. Due to the small vehicle size this option allowed the development of a relatively low cost propulsion system with velocity and electrical current measurement.

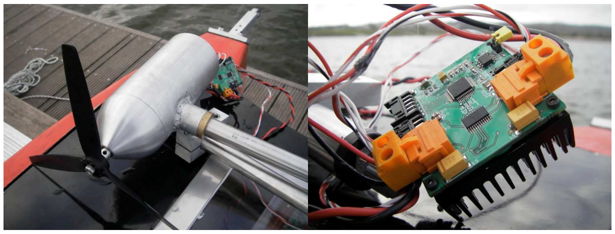

Figure 3. Thruster unit with embedded axis control electronics.

A dedicated thruster control board was developed, with local processing in an integrated DSP and with current monitoring (Fig. 3). The local motor controller includes the power drive along with the processing for velocity or force control and diagnostics and failure detection. The system has a CAN bus interface thus providing a standard interface and is integrated in the thruster enclosure.

For the ROAZ II system a pair of standard electric boat trolling motors we used. These allow a considerable increase of thrust force. Although with a lower voltage rating and higher nominal current, the available space for control electronics and power drive allows the system use.

A Roboteq power drive housed in the electronics box provides thruster power control.

C. On-board computer system and communications

The vehicles main on-board computer consists in low power single board computers. These are responsible for the mission control and vehicle navigation.

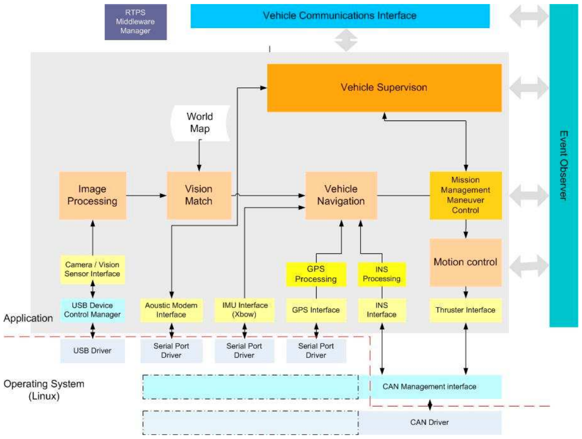

Figure 4. Vehicle software architecture.

Control, navigation and mission control are performed in a low power embedded computers running a modified Linux operating system (Fig.4)

On the ROAZ system CAN bus communications are are used between the central CPU and the thruster control nodes and other sensors.

Serial communication is used on the ROAZ and ROAZ II to read GPS and INS data, to receive sonar data (sidescan and altimeter) and in ROAZ II to control the thrusters.

Radio communications are achieved through an external IEEE 802.11 a b/g ethernet modem with external antenna (in various configurations and gains). Currently IEEE 802.11a is used since the operation in the 5GHz band provided clearly higher range and bandwidth in near water conditions in comparison with previous experience with 2.4Ghz Wifi.

D. Navigation

Both vehicles share the same navigation system and set of sensors.

Vehicle navigation and positioning uses a GPS unit for absolute positioning (Novatel SmartAntenna, superstar II) and an IMU sensor coupled with magnetometer providing orientation, attitude velocities and accelerations. The IMU used is a Microstrain 3DM-GX1 module combining three angular rate gyros with three orthogonal accelerometers and three orthogonal magnetometers outputs orientation, angular rate and acceleration at a rate of more than 50Hz.

Sensor fusion algorithms estimate the vehicle state required by control and mission application.

E. Power Supply

ROAZ vehicle uses a main power supply of 24V provided by a variable set of 3700 Ah 12V NiMh batery packs, housed in the hulls. From the base power line various DC/DC converters generate appropriate voltages for different vehicle subsystems and sensors, such as the main CPU board, IMU, GPS, communication systems or other payload sensors.

The sea vehicle ROAZ II power supply system is constituted by a bank of four 12V/56Ah navy sealed AGM (Absorbed Glass Mat) batteries housed in a waterproof Peli 1620 case, providing the 12V nominal voltage for the thrusters.

Inside the CPU case there is a 12V distribution/protection board handling power sharing for the motors, CPU DC/DC and the additional DC/DCs for all the other the electronic devices. Vehicle power supply is protected against surge and overcurrent system failures.

F. Payload

Payload sensors for the two systems depend on the vehicle size and operational requirements. Particular configurations address different mission needs.

For bathymetry and underwater bottom imaging an Imagenex SportScan dual frequency (330KHz, 800KHz) sidescan sonar is used along with a Imagenex 863 sonar altimeter.

A SW100 Glomo CTD is used for oceanographic data collection.

Bottom imaging capabilities provided by sonar sidescan can be used in search missions, such as in marine archeology or in case of corpse retrieval in sea catastrophe and disasters rescue and support operations.

III. VISION BASED TARGET TRACKING

With particular relevance for search and rescue missions, the vehicles vision system allows automated search and target tracking.

ROAZ and ROAZ II are equipped with conventional cameras (both for on board image processing and for video transmission).

ROAZ II system is equipped with a termographic infrared camera (Fig. 5) capable of resolution up to 0.1ºC of temperature difference.

Figure 5. ROAZ II Visibe and infrared camera.

The vehicles vision system is a particular application of a more general vision system developed for robotic applications (LSAVision).

Information from the low cost embedded robotics vision system (LSAVision) [11] is used to determine target relative position and orientation to the surface vehicle. Existing technology demonstrated on other stringent mobile robotics scenarios (such as ISePorto Robocup's robotic soccer team or FALCOS autonomous aerial vehicles) is applied to this case.

The vision system processes image in real time, with edge detection and object identification, extracting target image characteristics (position, orientation). Colour based image segmentation is used as a first stage in a pipeline structure with increased abstraction.

Currently one USB digital camera is used. It acquires images at 30 fps with a resolution of up 320x240 or 15fps at VGA resolution (limitation from the USB bus). At lower resolution it is possible to process 2 cameras in real time.

Lower stages implement image acquisition (Video4Linux camera interface) and image segmentation. The image processing threads are capable to process all the acquired images. This processing is mainly done in a colour-segmented image.

The colour segmentation algorithm implementation follows a very efficient method proposed in [1]. This process is still sensitive to lighting conditions.

Regarding thermografic images, a binary segmentation is performed extracting high intensity regions (corresponding to higher temperatures relative to the water).

Upper layers perform edge and blob detection along with object recognition. Only relevant features are processed. A set of additional modules performs statistics measurement, image calibration and overall control on elements to process.

The vision system allows the use of conventional digital low cost cameras, thermografic infrared cameras or can use dedicated hardware vision sensors (BoaVista system) with significant energy consumption reduction in image processing. Relevant image information can be retrieved by only one camera (distance to target and orientation measures are provided) although the vision system can incorporate stereo information for increased precision.

Target position in the image plane is related with its position on a world reference by a rotation and translation matrix. Th relation between a 3D world coordinate and a 2D image one is described by camera projection model.

Considering a pinhole camera model, image plane points relate to the camera frame points by the camera intrinsic parameters.

Using the camera extrinsic parameters it is possible to determine the correspondence between a point in an external frame.

The loss of 3D information in a monocular vision system can be retrieved in this case, if we consider the target to be at surface. This consideration is of particular interest since it is the case of floating bodies such as people lost at sea.

A four state kalman filter is used to estimate target position and velocities from the raw vision data.

In the problem statement the target is considered to be drifting on surface and if water current is relatively constant for both vehicles, both drift so the target velocity is not relevant. However it is assumed that the ASV can have a relatively complex and accurate navigation system providing a precision estimate in the earth fixed frame.

IV. CONTROL

A hierarchic architecture is considered to integrate the vehicle’s navigation and control systems and a hybrid systems framework was adopted in order to design control and navigation algorithms.

The global control design relies on the concept of manoeuvre, which is modeled by a hybrid automaton [14, 15]. This can be briefly described as a set of discrete states and transitions between them, being a set of controlled continuous flows associated with each one. The manoeuvre implementation involves not only the vehicle hybrids control law, but also the navigation filters. The control and navigation systems are integrated in the manoeuvre design. In addition, more complex manoeuvres can be obtained by the hierarchic composition of simpler manoeuvres.

The next figure depicts the information flow diagram

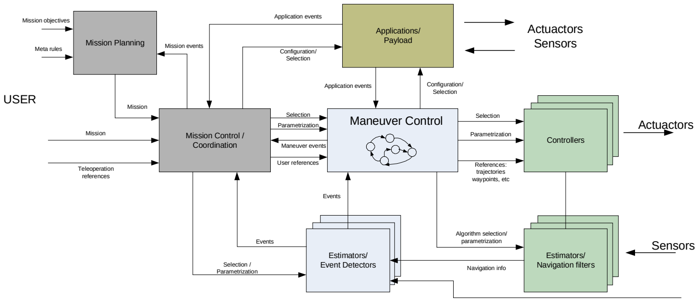

Figure 6. Control system architecture information flow.

Vehicle motion control uses information from the fused navigation information and mission objectives.

The vehicle mission can incorporate autonomous control such as automated search manoeuvres (lawnmow patterns, active search etc) and direct human supervision or teleoperation.

V. MISSION RESULTS

Both vehicles have been performing a various set of missions, ranging to subsystem test and validation to operational scenario ones.

Communication tests have been performed validating the use of Wifi comunications for short range video transmission and vehicle supervision. ROAZ has participated in a technology demonstration mission in the scope of the NATO Swordfish 2006 exercises performed near Troia, Portugal.

Figure 6. ROAZ ASV in the NATO Swordfish 2006 Exercises.

Bottom imaging missions have been performed near the shore in Matosinhos, Portugal with the ROAZ II vehicle and sonar sidescan sensor.

Figure 7. Image captured at test site with buoy and ISURUS AUV at surface. On top real image, real time segmented image (red, yellow) on middle and bottom (only segmented colours).

Vision based target tracking tests (Fig 7, 8) have been performed with different targets such as buoys or surfaced AUVs (Autonomous Underwater Vehicles) in the Douro River or the Montemor Canoying course.

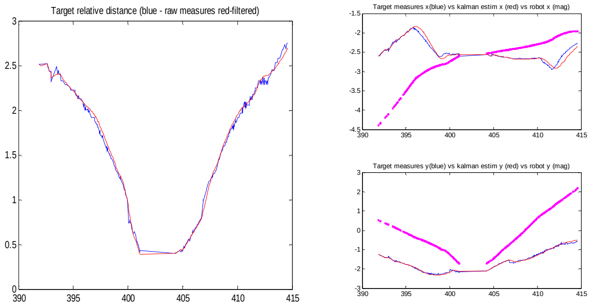

Figure 8. Target to robot relative measures.

The target relative position to the robot is given in figure 8 along with the filtered estimates used in control.

Preliminary tests with the thermographic camera have been performed (Fig 9) with high contrast detection in the infrared image for surfaced human bodies, even in difficult light conditions (low angles of incidence).

Figure 8. Visible spectrum (top) and infrared (bottom) image of a human body in water.

VI. CONCLUSIONS

This work describes the design and operational marine capabilities of the ROAZ and ROAZ II autonomous surface vehicles.

Mission tests and sea trials proved the operationally of both vehicles and demonstrated mission capabilities.

The real time vision processing system is described and results are presented in operational scenario. These results give confidence to the use of autonomous surface vessels as an effective and efficient tool to incorporate in marine search and rescue missions. Their capability of autonomous operation in extended periods of time, night operation and autonomous search can be exploited to augment current marine rescue human and technical infrastructure.

Further work is still necessary to throughout validate de approach under stronger varying light and wave conditions

In addition future work must be performed addressing the specific requirements of marine rescue such as reliability and operation in very though sea conditions and the integration of autonomous systems in a more complex and vast search and rescue scenario.

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