# Field experiments for marine casualty detection with autonomous surface vehicles

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***Abstract*—In this paper we present a set of field tests for detection of human in the water with an unmanned surface vehicle using infrared and color cameras. These experiments aimed to contribute in the development of victim target tracking and obstacle avoidance for unmanned surface vehicles operating in marine search and rescue missions. This research is integrated in the work conducted in the European FP7 research project Icarus aiming to develop robotic tools for large scale rescue operations.**

**The tests consisted in the use of the ROAZ unmanned surface vehicle equipped with a precision GPS system for localization and both visible spectrum and IR cameras to detect the target.**

**In the experimental setup, the test human target was deployed in the water wearing a life vest and a diver suit (thus having lower temperature signature in the body except hands and head) and was equipped with a GPS logger.**

**Multiple target approaches were performed in order to test the system with different sun incidence relative angles.**

**The experimental setup, detection method and preliminary results from the field trials performed in the summer of 2013 in Sesimbra, Portugal and in La Spezia, Italy are also presented in this work.**

## I. Introduction

Marine casualty detection with Forward Looking Infra-Red (FLIR) cameras [1] is one of the methods used in search and rescue at sea. Mainly for efficiency reasons, the typical setups use airborne FLIR systems with different degrees of autonomy in the target detection. Unmanned surface vehicles (USV) can provide a useful resource for assistance in search and rescue at sea [2]. This work is developed in the context of the European Union FP7 Research project ICARUS aiming to integrate robotic tools for large scale disaster scenarios. In particular for the marine environment scenario, a large scale disaster is addressed with possibly a large number of casualties in the water needing rescue. The proposed robotic rescue support solution comprises aerial robots for victim localization, rapid USVs for deployment of assets in the area and in particular autonomous lifesaving rafts. One of the USV requirements is to be able to detect victims in the water, this has two purposes: to contribute in the detection itself and provide rescue and for obstacle avoidance. In addition, humans in the water detection is a relevant capability for unmanned maritime systems, with applications in search and rescue operations in general. In this work are presented the results of human detection field experiments with an infra-red camera and a color camera onboard of the autonomous surface vehicle ROAZ [3]. The experiments were performed in Sesimbra, Portugal in cooperation with the Portuguese Navy and in La Spezia, Italy at the NATO CMRE (Centre for Maritime Research and Experimentation) facilities.

Multiple vision based methods have been used [4] [5] for target detection at sea. FLIR has been used in aerial search [1], [6] along with color based contour image search [4]. From histogram analysis and probabilistic similarity approaches such as the one presented by [5] to dim point morphological based operations [6], the proposed methods balance computational requirements to robustness facing the environmental conditions. Other approaches treat directly the continuous video stream taking advantage of target dynamics, such as the spatial-temporal intensity projection method proposed by [7].

Our approach follows a decoupled structure with the analysis of thermographic and color images separated from the target tracking. We use simple intensity (for the infrared image) and color segmentation detectors for each frame to produce a set of possible target candidates. These are then tracked in order to eliminate reflections and false positives by the target dynamics.

The paper is organized as follows: the ROAZ autonomous surface vehicle is described in section III followed by the description of the human target detection process at sea. The experimental setup is described in section V and some of the preliminary results obtained in the tests are presented in the following section followed by concluding remarks.

## II. ICARUS MSAR problem

The maritime search and rescue scenario (MSAR) is one of the ones addressed in the FP7 project ICARUS led by the Belgium Royal Military Academy [8]. This large scale European project (with 24 partners across Europe) aims to

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develop and integrate robotic tools in mass rescue missions. It comprises two operational scenarios, one urban search and rescue (such as a large earthquake) and a maritime one.

For MSAR scenario a large scale maritime disaster is addressed, with a large number of human victims on the water. One example of a possible scenario could be a passenger ship or ferry accident.

In the Icarus MSAR response context, a set of robotic tools are envisioned. A high autonomy fixed wing unmanned aerial vehicle (UAV) is considered for large area survey and identification of persons on the water (using a specifically developed infrared sensor).

For aiding in the rescue activities, a fast USV is also considered as a means to rapidly deploy assets in the accident zone. This USV will carry a set of unmanned autonomous survival capsules (UCAPS) that will be deployed at convenient locations and are able of being self-propelled towards the victims or their vicinity. Once there, they inflate as a normal liferaft providing first response rescue. In addition, a set of smaller rotary wing UAVs are considered for UCAPS guidance and short range victim location and situation awareness. The capsules can also be directed by the USVs when they are capable of locating relevant targets.

In this scenario, the USVs must be able to operate safely in the environment. For that operation, obstacle mapping and avoidance capabilities must be developed. In particular, with the existence of possible human victims on the water the USVs must be able to detect and avoid them. Also, even when operating at a safe distance the capability of locating victims on the water can be used both for guidance of the rescuing UCAPS and, in general, to improve the global situational awareness of the human rescue teams at the site.

For this requirement the USVs are equipped with a set of sensors namely infrared and color cameras, laser rangefinders and radar.

In this work the problem of detecting victims on the water with vision systems onboard of an USV is addressed. In particular the first experiments and preliminary results towards this objective are presented.

## III. ROAZ USV

The ROAZ vehicle (figure 1) is a 4m long twin hull autonomous surface vehicle equipped with a LWIR (Long Wave Infra-Red) and a colour digital camera. Both images are processed in real time in the onboard CPU that also provides the vehicle autonomous capabilities.

For navigation purposes the vehicle uses a precision L1/L2 GPS receiver (Septentrio PolaRx2) and a inertial motion unit (Microstrain 3DM-GX1) providing attitude information.

Propulsion is achieved through the use of two 2kW electric thrusters with the vehicle reaching a maximum speed of 10 knots. A set of LiFePo batteries provides up to 8hr of autonomy.

A IEEE 802.11a wireless link is used for communications. This link allows the vehicle supervision from a remote console, mission definition and streaming of sensor data.

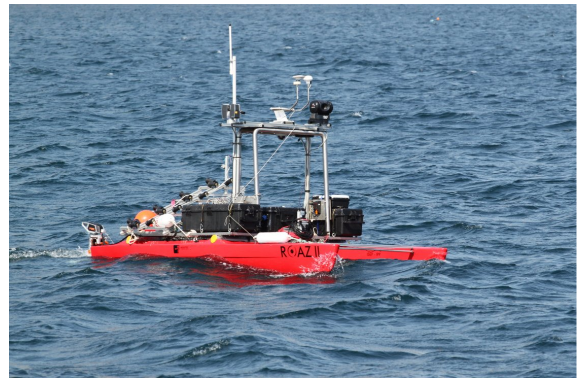

Fig. 1. ROAZ USV

Roaz has also in a lowered platform a sidescan sonar (Imagenex Sportscan), a multibeam sonar (Imagenex DeltaT) and a single beam echosounder used for underwater environment modelling and bathymetry purposes.

The vehicle has also a broadband radar and can be equipped with a LIDAR sensor for above water obstacle detection and environment modelling.

The onboard computer runs the autonomous control software in a Linux operating system environment and using the ROS (Robotic Operating System) middleware framework.

The vehicle can perform autonomous tasks defined either as waypoint or trajectory defined manoeuvres or sensor based control tasks. When within the communications range it can also be teleoperated from a remote console. It is also possible to override the computer based control onboard the vehicle.

## IV. Marine casualty detection

### A. Horizon detection

In order to reduce the image search space in the target detection process a relevant task is to detect the horizon in the image and perform the search below it (and in a reduced margin around it).

One good characteristic of the infrared images at sea (during the day) is that in open sea the horizon can be clearly identified.

Multiple methods have been proposed in the literature for horizon detection at sea. These range from multiple visual clues approaches [9], dark channel formulation for fog and haze processing [10] or spectrum based analysis for cloud and artifact removal coupled with relaxed elliptical fitting (to reduce computational cost) for detection as presented in [11].

We use for horizon detection a simple edge detection coupled with a Hough transform for detecting the large linear edges. The collinear segments are then grouped together and the largest candidate group is chosen.

This approach is not robust when the image has large linear edges from other elements in the scenario such as ships at relatively close range or other man made structures. Also in bad weather conditions it can be difficult to obtain a coherent set of edges.

However in a large number of open water situations this horizon detection method is feasible leading not only to a reduced image search space but also to additional roll and pitch information. One can also note that estimated pitch and roll information from the navigation system can also be used in horizon candidates discrimination.

### *B. Target detection*

In the IR spectrum the human target at sea has a high contrast in relation to the environment and thus facilitates its detection (even for small targets as the one in figure 3, marked in red). The main problems are sun reflections at the surface and wave foam. However both are transient and can be removed by multi-frame analysis. In the color image, target detection poses additional difficulties. Here the image processing is much more dependent on the global illumination settings and in addition in general there is no prior color information regarding the targets. In the experiments described in this work the subject targets were using orange colored life saving vests, thus allowing for the use of color based image segmentation in the detection process.

The infrared image $I$ is first subject to an histogram expansion process in order to improve contrast.

$$I_{exp} = histnorm(I) \quad (1)$$

Next, a threshold is applied to the image in order to detect high temperature spots. When horizon information is available, high intensity blobs bellow the horizon (in fact bellow a certain margin above it in order to detect in the horizon targets) are segmented.

$$I_{labelled} = blob\_label(I_{exp} > threshold) \quad (2)$$

Each blob centroid is then a possible target candidate for the frame. In the color image a similar process is performed, here for the target detection a color based segmentation is performed on the region of interest. This color segmentation is performed in YUV color space with the color limits previously defined in a lookup table.

The detected frame target candidates can then be used in a EKF based filter to eliminate reflections and false positives.

Target 3D positioning can be determined from multi-camera information. In our case, this can be done with images from the with one image from the infrared camera and other from the color . Using the standard pinhole camera model, the image points (for an undistorted image) in homogeneous coordinates are given by:

$$\mathbf{x} = \mathbf{K}[\mathbf{R}|\mathbf{t}]\mathbf{X} \quad (3)$$

where $\mathbf{K}$ are the intrinsic parameters, $[\mathbf{R}|\mathbf{t}]$ are the camera extrinsic parameters and $\mathbf{X}$ is the 3D point in the world frame (usually this is the vehicle body fixed frame).Each camera provides a set of $\mathbf{x_i}$ points. These, when corresponding to the same real world point can be combined in a multi view geometry to provide $\mathbf{X_i}$. For each corresponding pair of target image points (target blob centroids] $(\mathbf{x_1}, \mathbf{x_2})$ on different cameras (for the same target) the relative 3D positioning is determined by triangulation or by solving the overdetermined system:

$$\begin{cases} \mathbf{x_1} = \mathbf{K_1}[\mathbf{R_1}|\mathbf{t_1}]\mathbf{X} \\ \mathbf{x_2} = \mathbf{K_2}[\mathbf{R_2}|\mathbf{t_2}]\mathbf{X} \end{cases} \quad (4)$$

## V. EXPERIMENTAL SETUP

The ROAZ autonomous surface vehicle was used to gather sensory data from the possible targets on the water.

The vehicle is equipped with a L3 ThermalEye 5000xp infrared camera pan and tilt unit (used in a fixed predefined and precalibrated configuration). This IR camera has a very narrow field of view of 24ºx18º and has a minimum focusing distance of 6m. Its composite video output is acquired by a Sensoray2225 framegrabber, producing 320x240 frames at 30 fps. Color images are obtained from a Bashler acA1300-30gc, GigE digital camera, with 1278x958 of maximum resolution and 30fps of maximum framerate. However due to restrictions on the available bandwidth and disk space these images where acquired at 15fps. The camera has an external trigger that was used to timestamp the images. The corresponding IR images where also timestamped.

The onboard computer was also running the Chrony clock synchronization daemon with Linux PPS from the GPS, in order to synchronize internal clock to GPS time, and assure precise timing information.

The infrared camera intrinsic and extrinsic parameters were calibrated with a pre heated calibration target. For the color camera a standard chessboard pattern was used for prior camera calibration. This calibration procedure also allowed to obtain the essential matrix relating both cameras and thus the stereo calibration parameters for the IR and visible camera pair.

A set of targets was used in the experiments: a fixed orange buoy for validation and functionality verification purposes and a person in the water. In addition two small USVs were used as moving obstacles, one of them carrying an orange life vest.

The position of the person in the water is recorded with a GPS logger in a small watertight case. A ublox NEO6T GPS receiver is used, and raw satellite data is recorded for posterior processing.

The victim target was wearing an orange life vest and free floating on de water. The choice of using a colored marker for the targets was made at this stage to simplify the problem. In particular allows the early test of multiple visible and infrared detection approaches, and to facilitate the early test and integration with other Icarus project workpackages (such as aerial recognition). In addition, this simplifying assumption also corresponds to possible real rescue situations at sea where the victims have lifevests on. In the subsequent work additional detection methods in the visible spectrum are to be investigated.

Sensor data was collected with the ROAZ USV approaching the targets from different angles and with different angles in relation to the sun. The experiments (in Portugal and Italy) where performed at different times of the day.

## VI. Results

### A. Tests with the Portuguese Navy

A set of tests were performed in cooperation with the Portuguese Navy and during the REX2013 (Robotics EXercise 2013) exercise promoted by the Portuguese Navy through its Naval Research Center (CINAV - Centro de Investigação NAVal). These tests were performed in Sesimbra, Portugal and were developed partially in the context of the european Icarus project in which the CINAV is also a partner.

Fig. 2. Tests in Sesimbra, NRP Bacamarte support vessel on (left) and target detection experiment (right)

One example of human target detection in the infra-red image is presented in figure 3.

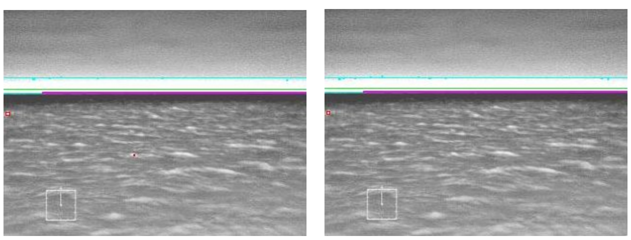

Fig. 3. IR Target detection

Here on the left one can observe 2 detected targets, the human on the far left and a sun reflection on the water in the middle. These false targets can however be discarded by the image dynamics as it is shown on the frame on the right taken immediately afterwards. On the images is also represented in magenta the detected horizon line.

The color image is shown in figure 4 on the right with the corresponding infrared one on the left. The difference of field of view and focal length can easily be observed in the figure.

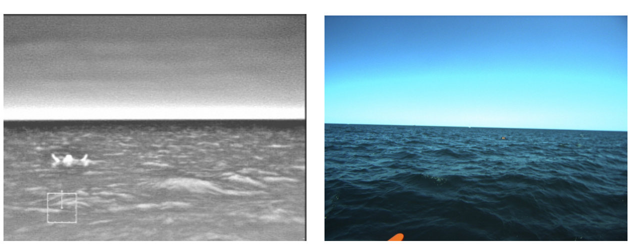

Fig. 4. Human on the water, IR raw image (left) color image (right)

In these experiments the horizon detection was successful in the vast majority of frames (more than 95%) since the scenario is open water with very low visual clutter at the horizon.

### B. Tests in La Spezia

There where also performed target detection tests in La Spezia, Italy hosted by the NATO CMRE in the context of the Icarus project.

These experiments aimed to perform data collection for posterior analysis in a different scenario with increased visual clutter (since performed in the interior harbor bay). In addition to the victim in the water, two other INESC TEC USVs where also used as moving obstacles.

Fig. 5. Human target tests in La Spezia

In the figure 6 a plot of the trajectory performed by ROAZ and the location of the test victim is presented for a test run in La Spezia.


Fig. 6. Roaz trajectory with a victim on the water

One snapshot (infrared and visible) of the victim in this test, with the harbour in background is presented in figure 7. In this orientation a strong sun reflection in the water is shown in the color image, posing problems in terms of image processing. For the same frame in the infrared image the human target is clearly discernable.

## VII. Conclusions

In this paper we present preliminary work towards the human target tracking on the water in the context of marine search and rescue missions.

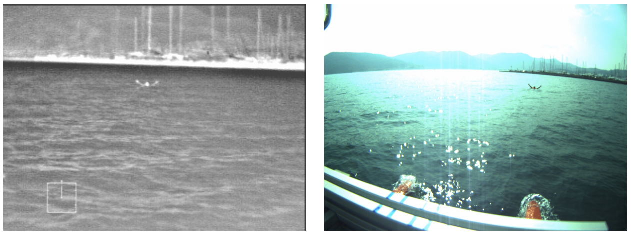

Fig. 7. Human on the water at La Spezia tests, IR raw image (left) Color image (right)

The ROAZ autonomous surface vehicle equipped with a infrared and a color camera was used to detect humans in the water. In the experiments described in this work the subject targets were using orange colored life saving vests, thus allowing for the use of color based image segmentation in the detection process.

The experiments were conducted in the context of the European FP7 research project ICARUS focusing on robotic tools for search and rescue and were performed in Sesimbra, Portugal and at the NATO CMRE in La Spezia, Italy.

The tests where performed with autonomous surface vehicle in order assess the feasibility of using thermographic imaging and color imaging to detect victims on the water and allowing short range rescue aiding and obstacle avoidance tasks.

From the results obtained so far the use of LWIR images has shown promising results for detection even with a small height over water (about 2m) for the camera placement.

The combined use of IR and visible spectrum images also allows a much better discrimination of targets and false positive rejection.

These preliminary results and field trials constitute a starting point for the development of robust multisensory obstacle detection and victim location. Further refinements and analysis is to be directed at developing robust algorithms both for horizon detection and victim location. Extensive work will be performed on the multi-target filtering and tracking process along with consistent obstacle mapping and avoidance behaviors for the autonomous surface robots.

This work has also to be integrated in the larger context of a mixed initiative (with both human and robotic tools) global rescue operations framework.

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