Radar Based Collision detection developments on USV ROAZ II

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***Abstract*- This work presents the integration of obstacle detection and analysis capabilities in a coherent and advanced C&C framework allowing mixed-mode control in unmanned surface systems. The collision avoidance work has been successfully integrated in an operational autonomous surface vehicle and demonstrated in real operational conditions. We present the collision avoidance system, the ROAZ autonomous surface vehicle and the results obtained at sea tests.**

Limitations of current COTS radar systems are also discussed and further research directions are proposed towards the development and integration of advanced collision avoidance systems taking in account the different requirements in unmanned surface vehicles

I. INTRODUCTION

Research in unmanned marine systems has experienced a strong increase in the last years leading to the emergence of multiple systems with various operational degrees.

Unmanned surface vessels have been applied both to security and military applications [1] or civil oriented ones such as scientific data gathering [2], [3] or multiple vehicle operations support [4]

Obstacle detection and avoidance is a clear issue for increases in decision autonomy and to further extend the range of missions for these type of systems

In this paper we present the integration of collision detection capabilities in the autonomous surface vehicle (ASV) ROAZ II. A modular and flexible Command & Control (C&C) framework was used allowing mixed-mode control for the system with human supervision and actuation on the control loop. A target collision detection system based on radar information and remote vision was tested on the vehicle. Preliminary tests were performed with the ROAZ II ASV at the northern Portuguese shore.

Obstacle avoidance has been a long-standing topic of research in the mobile robotics community. Ranging from reactive approaches [5] to deliberative ones requiring re-planning or behavior selection [6] solutions have been proposed to the motion planning and control problem in different mobile robot environments.

Motion control for autonomous surface crafts have been addressed [7, 8] without the presence of obstacles.

Marine scenarios pose harsh environmental restrictions in terms of sensor requirements. Adequate sensor capabilities are necessary in order to provide real-time collision awareness.

Conventional ships rely mainly in radar and visual information for collision detection. Visual information is used only at close range since rules of traffic [9] should ensure safety when all the vehicles present are identified. In addition, sound and light warnings are used in frequent low visibility conditions. Thus radar sensors stand as the most relevant component in target detection for marine surface vessels.

Collision detection and obstacle avoidance techniques based on environmental modeling from multiple sensors in fast moving unmanned vessels have been proposed [10] with deliberative approaches at long range and reactive ones in near target vicinity.

Obstacle and collision avoidance greatly improves from vehicle signaling capabilities in relation to other marine agents. Here AIS (Automated Identification Systems) play a relevant role. A discussion on communication issues and AIS for a scientific purpose unmanned surface craft is presented in [11].

In the following section the problem of collision detection for autonomous surface robots is discussed. Both sensory and functional requirements are discussed in view of a possible

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fully autonomous operation or with human presence in the control loop. The ROAZ II unmanned surface vehicle (USV) is presented in section III followed by the collision detection infrastructure in terms of hardware and software. Sea trials and test experiments are discussed in section V. Finally some concluding remarks and future research are addressed.

II. Collision detection in Autonomous Surface Vehicles

A. Problem

The success of operating unmanned surface vehicles relies heavily on its capabilities to detect and avoid collisions with harbour walls, shallow waters, other surface vehicles, etc. Each of these items is detected using a specific technology and several sensors or data sources may be used to for a single item. For example, an ARP Radar is able to detect the presence and course of additional surface vehicles at distances higher than 0.5 miles, while a video camera is used for short distances. Collision detection with shallow waters requires the availability of a height map. The isolation of these features in a modular system provides integration support for several data sources, allowing the integration on any surface vehicle and for a variety of missions

Although similar to manned ships, the problem of target detection in autonomous surface vessels has some distinctive requirements.

In relative small size (compared to standard ships) USVs low height radar antenna positioning brings problems with high waves occlusion (particular relevant in small targets) and water reflectivity. For autonomous or semi-autonomous operation, the integration with the vehicle control system must consider the human operator when available. Not only the detection must be performed along with predicted trajectory and corresponding correcting maneuver issued when necessary. But also, a situation assessment must be provided to the human supervisor in a consistent way. This entails the remote availability of additional information such as detailed video radar or video.

Since many of the COTS (Commercial Off-The-Shelf) radar systems can provide automatic target tracking these can provide target information for collision analysis.

In order to identify potential targets three values are used:

CPA (Closest Point of Approach) – Estimated distance between the USV and the detected object at the time instant where such distance is minimal.

TCPA (Time to closest point of approach) - estimated time that it will take for the two objects to reach their minimal distance (CPA).

CD (Current distance) – current distance between USV and target.

TCPA values can be positive or negative, depending on the convergence or divergence of vehicles. When target and ship are heading towards their Closest Point of Approach, the TCPA will assume a positive value and begin decrementing, should course and speed remain unchanged, until minimal distance is reached (at TCPA = 0). However, the TCPA will have a minus sign, if its absolute value is increasing continuously. This happens when vehicles are moving away from their CPA; It will not be reached unless if changes in course or speed occur. Therefore, two targets may have equal CPA values but pose different collision risks, depending on TCPA sign (if sign is negative, it will not pose a threat based on CPA alone)

B. Classification

Target classification in terms of collision threat can be performed by analysis on the relevant relative trajectory parameters. A set of perimeters (Figure 1) around the USV can be defined in order to assess of collision danger and to decide appropriate measures.

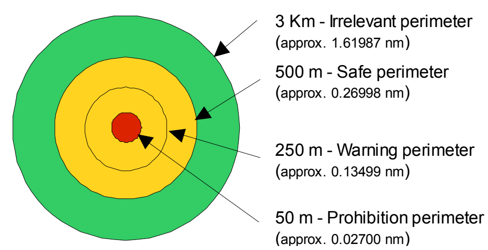

Figure 1.Safety perimeters for the USV.

The reconfigurable perimeters were set as follows:

Irrelevant perimeter (3km, approx. 1.61987 nautical miles) - A threshold of 3km guarantees that targets operating in this region are highly unlikely to pose a threat to the USV.

Safe perimeter (500m, approx. 0.26998 nautical miles) - A threshold of 500 meters guarantees a security perimeter from passing vehicles.

Warning perimeter (250m, approx. 0.13499 nautical miles) - A threshold of 250 meters means that the approaching vehicle could pose a considerable threat to the USV.

Prohibition perimeter (50 m, approx. 0.02700 nautical miles) - is the minimum distance allowed. A vehicle with a CPA below this value has a very high risk of collision. 30 meters is the minimum limit of the Radar's visibility, therefore the threshold needs to be reasonably greater

Targets can be classified according to their potential threat in terms of collision prediction. Different risk levels of collision for each target can be identified. These levels are based on the current and potential risk of collision which are represented by the current distance and CPA to a particular target. As stated before, TCPA sign will determine CPA evaluation. A CPA with negative TCPA value will be considered as being above (or outside) the Irrelevant Perimeter (regardless of its true value), and current distance will be the determining factor for target classification.

A target with a distance and CPA above (or outside) the Irrelevant Perimeter is classified as **No Threat**.

Should its CPA or CD cross the Irrelevant Perimeter, but neither value crosses the Safe Perimeter, it is classified as **Low Threat**.

Similarly, if its CPA or CD crosses the Safe Perimeter but neither value crosses the Prohibition Perimeter, it is classified as **Potential Threat**.

Finally, should its CPA or CD enter the Prohibition Perimeter, the target is classified as **Dangerous**.

III. ROAZ USV

The ROAZ II autonomous surface vehicle [3,4] (Figure 2) consists in a twin hull autonomous robot capable of operation at sea in autonomous or semi-autonomous mode. It has a on-board computer responsible for autonomous control and navigation, multiple antenna GPS receiver for RTK positioning and orientation determination and an inertial navigation system. It is powered by a set of heavy-duty traction type lead-acid batteries and to electrical underwater thrusters.

Figure 2. ROAZ II Autonomous Surface Vehicle.

It has a day & night video camera along with a thermographic one for remote perception and security applications. It is also equipped with a sonar altimeter and a sidescan for bathymetry and ocean bottom imaging purposes. Additionally it has a CTD probe for oceanographic missions.

The on board system communicates with a remote supervision console trough an IEEE801.11a radio link. On board omni-directional antennas are used and on shore sector scan directional antennas allow an operational communication link up to 3km (depending on relative antenna height) without amplification.

The prototype is part of a research program in autonomous marine systems led by ISEP autonomous systems lab. It has performed multiple bathymetry and security related missions either at sea or estuarine environments.

For this collision tests experiments it carried a Radar system, an additional video camera, and an additional electronics box.

IV. COLLISION DETECTION INFRASTRUCTURE

The dedicated obstacle detection hardware subsystem consists of: a Furuno radar (Figure 3) antenna and control unit, a GPS unit and, a pan-tilt-zoom video camera, and a separated wireless Ethernet communication link. Radar control system on-board was responsible for integration with dedicated GPS information. The electronics were housed in a separated watertight enclosure thus allowing easy deployment in other vehicles.

Figure 3.Furuno radar, pan&tilt camera and watertight electronics boxes.

Video information, radar image and messages were transmitted trough this link to the C&C software running on a remote control station. The ROAZ USV was controlled also remotely through either in tele-operation mode or in autonomous mission control (Figure 4).

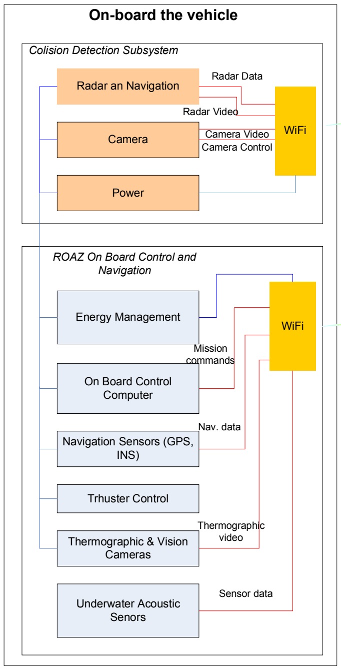

Figure 4.System architecture

A more detailed view of the hardware implementation for the experimental collision detection payload on-board of the USV can be observed in Figure 5.

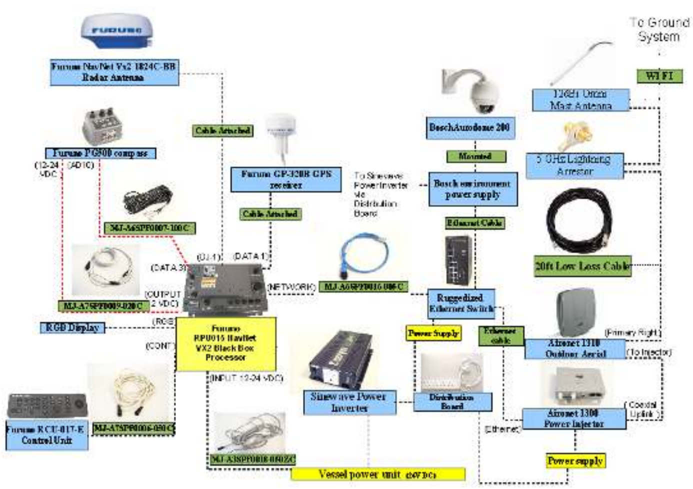

Figure 5.C&C Platform architecture.

The collision avoidance software (USVCAD) installed in the operator's console provided a full 3D GIS visualisation, with the ability to analyze mission specific geographic data. The view was complemented with the readings from the Furuno equipment and alerts were presented to the operator when a collision route was detected. The video streaming from the radar and camera were also presented in real-time, aiding the operator in the analysis of the situation.

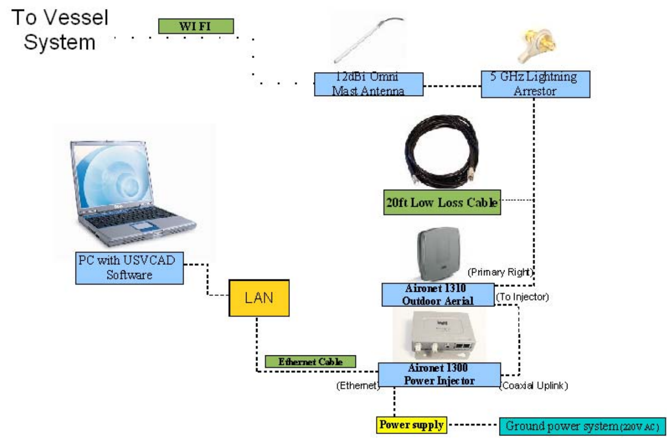

Figure 6.C&C Land segment.

The software solution of the collision avoidance system is based on the generic Critical Software's C&C Platform, (Figure 6) with specific customisation and new development. The diagram below introduces the main software components to be used on the solution as well as the interactions with the external world.

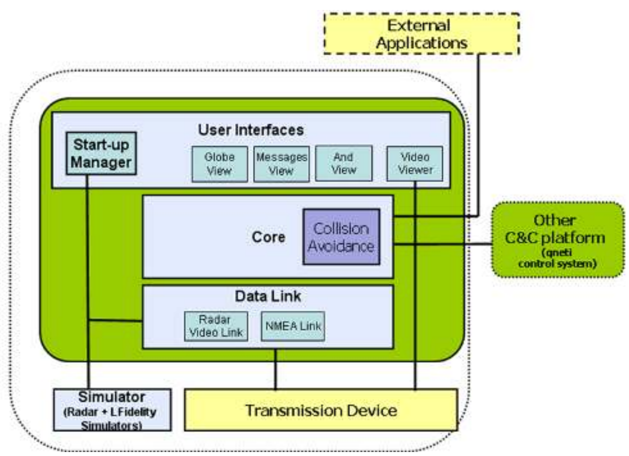

Figure 7.C&C Platform architecture.

A specific datalink to deal with the NMEA and Video streams were developed, as a specific user interface to display collision alarm messages

V. DETECTION EXPERIMENTS

Collision detection tests were performed at sea near Leixões harbour on the northern Portuguese coast. The test scenario provided also relevant conditions by the combination of clear water environments to cluttered ones such as on shore, harbour structures and heavy marine traffic.

Figure 8.Radar target (left) and test support boat (target boat).

For the sea tests a small support boat (5.2m length) was used to provide a radar target (see Figure 8). In order to be detected by the radar system on the USV, various sets of radar targets were used (since the boat has a very low radar signature due to its small size and construction materials).

In addition regular vessel traffic near Leixões harbour was used in the validation process.

A control station was mounted on shore (within radio communications range). This station comprised the ROAZ host control console and a separate computer running Critical Software C&C infrastructure with target detection and monitoring. The ROAZ console was used for mission definition and upload, for real-time telemetry and also for remote tele-operation when necessary. In addition the standard ROAZ operation infrastructure included a land based DGPS station and wireless communication antennas. The separation of the C&C infrastructure and the ROAZ autonomous control system allowed the validation of target detection methodologies and also the independence of tests in regard to a particular USV system.

Multiple target collision trajectories were tested using the support boat. These included approximation with and without interception from various angles: frontal, rear, perpendicular from port or starboard and oblique approaches (frontal and rear ones at 45º). Target trajectories relative to the USV varied from approaches entering and leaving the inner collision alarm zones to ones intercepting only outer alarm perimeters.

The tests were performed under different weather conditions ranging from heavy rain to clear weather. These conditions had strong impact on radar performance requiring multiple configurations for sensor parameters. The system was able to detect and track incoming vessels from fishery trawler to cargo ships, correctly issuing different levels of collision warnings and determination of the CPA and TCPA.

Regarding the small target boat, results were limited by the relatively low height in the antenna and radar target position on both vehicles, and radar limitations. Occlusion by waves was detected in and low radar signature for the target was also a limiting factor.

The Furuno radar presented severe limitations regarding automatic target tracking, allowing only target acquiring and tracking on the 2.5 mile range (without option to configure), thus restricting the detection of small boats at large distances. Additionally radar restricted reconfigurability coupled with the low antenna positioning in the tests, precluded the use of the same configuration for detection of large at long ranges simultaneously with efficient detection of very small targets at close range (less than 200m)

Near shore operation with moving land targets and large reflections from structures lead to a compromise needed by small gain to overcome land targets and high gain to detect small obstacles.

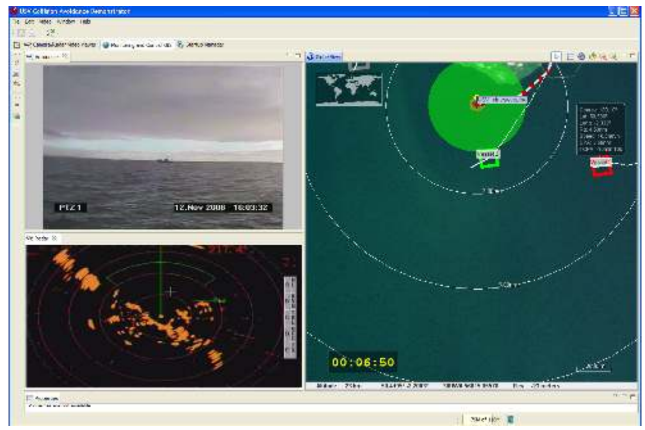

Figure 9. Target detected and leaving closest approach zone.

Within 2km range it was possible to establish IEEE 802.11a radio communications with standard access points and sector antennas on shore with real-time video link (2 cameras, visible and thermographic one) and video radar information (see Figure 9).

Clearly the main problem detected was the difficulty in detecting small targets at close distances. In this case standard radar approaches proved to be very limited. Considering the possible operating scenario for the USV and its relative small size, further work must address collision detection and target tracking for small obstacles at close range.

VI. CONCLUSIONS

The problem of obstacle detection for avoidance in unmanned surface vessels was addressed. Specific requirements for small surface robotic vehicles were taken in consideration along with the operation in mixed-mode with human supervision in the control loop or in fully autonomous control.

A C&C framework was used to validate target detection tests and collision avoidance. These tests used information from radar for automatic detection and vision information for operator situation assessment. Due to the specific validation purposes, a separate approach was taken in what regards the vehicle control system (ROAZ autonomous control both on-board and supervision land console) and the separate USVCAD C&C software used to test target detection.

Video image real time transmission coupled with radar data, as expected, proved to be valuable in tele-operation and human supervision tasks. The augmented environmental perception provided

The Furuno radar system proved to be strongly inadequate for the sensory requirements. Its automatic target-tracking module was very limited (both in bearing and on range).

Radar gain adjustments were only possible manually and were difficult to obtain with a small antenna height in relation to water and on cluttered environments.

Target classification and collision alarms were correctly issued (subjected to the limitations on the radar equipment) for the multiple relative trajectories tested and provided thus an automated situation assessment in terms of obstacles.

Standard COTS radar systems are designed for manned operation relying on video radar image interpretation by the human pilot and to provide early obstacle awareness. In USV systems and for short range in particular, more advanced solutions relying in automatic video radar analysis and artificial vision techniques are necessary and will be explored.

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