

# A ROADMAP TOWARDS THE AUTONOMOUS SHIP: THE MARIN R&D PROJECT

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**Abstract.** The “Autonomous Ship” is the new technological paradigm which is driving the trend for increasing ship automation. In this context, Fincantieri Nextech launched in 2019 the MARIN (Monitoraggio Ambientale Remoto Integrato Navale, Naval Integrated Remote Environment Monitoring system) R&D project, sponsored by Regione Puglia within the framework of “Contratti di Programma”. The objective of MARIN project is to set-up and test at sea a technological demonstrator of the enabling technologies for autonomous navigation. The demonstrator platform is the TESEO I, an experimental vessel jointly developed by NAVTEC and Tringali Shipyard as part of a previous research project, with subsequent proper adaptation to the needs of the MARIN project. Fincantieri Nextech, through its R&D site in Lecce, is in charge of the auto-remote control of the vessel and the of the overall technological integration. The other partners are RINA Consulting, through its operational site in Lecce, in charge of the realization of an innovative Thermal-Acoustic Surveillance System and Co.M.Media, a ICT company based in Lecce, in charge of the operational demonstration of a tethered aerial drone acting as additional optical sensor. The paper presents a technological overview of the research project and its achievement, including the preliminary results of the 2021 sea tests.

**Keywords.** Autonomous Vessel, Situational Awareness, Artificial Intelligence, Collision Avoidance.

## 1. Introduction

The maritime sector is experiencing in these last few years a clear technological trend from Electronics-aided Navigation (E-Navigation) towards A-Navigation, (*Autonomous Navigation*). On the other hand, given the fact that the enabling technologies for autonomous navigation still needs further development and systematic testing being ready for operational deployment and considering the immaturity of the relevant normative and legal context, we believe that in the next decade the majority of ships will still be manned, albeit with a skeleton crew supported by increasingly automatic systems onboard and highly-skilled human operators in Remote Control Centers (RCC) ashore, hereinafter referred to as “auto-remote” ship operations [1].

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Within this context, we address in this paper the technological challenges of auto-remote ship operations with reference to the know-how and operational experience gathered in the R&D project MARIN, aimed at the development of the enabling technologies for auto-remote ship operations and their assessment through sea tests on a technological demonstrator, the TESEO I, an experimental vessel jointly developed by NAVTEC and Tringali Shipyard as part of a previous research project.

For the purpose of MARIN project, TESEO I was refitted in order to enable remote control and monitoring from a ground station acting as RCC. The MARIN Unmanned Marine System (MARIN-UMS) demonstrator incorporates a suite of state-of-the-art detection sensors along with two innovative systems, namely a thermal-acoustic surveillance system, developed by RINA Consulting, and an optical surveillance system, realized by Co.M.Media by means of a tethered-drone.

These sensors provide the Remote Operator ashore with an enhanced level of perception of the environment around the vessel, through the implementation of *Sensor Fusion*, *Artificial Intelligence (AI)* and *Augmented/Virtual Reality (AR/VR)* techniques.

The combined information from the sensing system is used for collision detection, advising the Remote Operator on the risk of collision, suggesting the appropriate *Collision Avoidance (COLAV)* maneuvers and, upon operator approval, automatically actuating the same by means of an innovative Auto-Pilot system.

## **2. Overview of MARIN Unmanned Demonstrator**

The MARIN-UMS system is composed of three main functional blocks:

- The Extended Robotic Platform, consisting of:
  - Auto-remote Surface Vessel (ASV).
  - Tethered Unmanned Aerial Vehicle (UAV).
  - Acoustic-thermal Surveillance System.
- Ship-Shore Communication System (SSCS).
- Remote Control Center (RCC).

### *2.1. Extended Robotic Platform*

#### *2.1.1. Auto-remote Surface Vessel*

The ASV sub-system of MARIN-UMS consists of the following elements:

- The surface ship platform, comprising hull and standard onboard equipment.
- The sensing system, comprising the standard navigation systems (according to Class) and the Situational Awareness Advanced Sensor Suite (SAASS), which supports the *Enhanced Situational Awareness (E-SA)* functions.
- The Auto-remote Control System (ACS) for the management of the auto-remote functions.
- The ship-side component of the SSCS.

The surface ship platform was the TESEO I, an experimental vessel jointly developed by NAVTEC and Tringali Shipyard as part of a previous research project.

The auto-remote control of the propulsion (uncoupled port and starboard shaft propellers) and steering (coupled rudders and bow-thruster) devices was performed by the proprietary Extended DP (EDP) control system, able to automatically govern the ship over the whole operational speed range (from 0 up to 10 knots) through a combination of DP (Dynamic Positioning), Heading Control (HC) and Track Control (TC) logics.

#### 2.1.1.1. Enhanced Situational Awareness

To achieve the E-SA required for auto-remote operations, it was necessary to integrate the standard navigation equipment (i.e. GPS/AIS) with advanced additional sensors; accordingly, the SAASS included the following items (see Fig 1a):

- Infra-Red Electro-Optic (EO-IR) sensor
- Video 360° system
- 3D 360° LiDAR scanner
- Short-range high-resolution K-band radar



**Figure 1a.** SAASS.

**Figure 1b.** “Stitched” front view.

**Figure 1c** “Stitched” rear view.

further complemented by an Inertial Motion Unit with a built-in Inertial Navigation System (IMU-INS). The visual perception function for MARIN-UMS was accomplished by the video 360° system and by the EO-IR sensor; for the present application, the video 360° system consists of two modules, each of them assembling three day / night visible cameras (see Figs 1b, c from [2]): in order to obtain a smooth gapless 180° view from each module, it was necessary to “stitch” together the images from individual cameras.

The primary task of the EO-IR, mounted atop of the wheel-house, is to replace (and enhance) the human vision of the master from the bridge windows.

To make-up for the lack of depth from the 2D cameras, a marine LiDAR sensor was installed, capable of a continuous 360° 3D scanning of vessel’s surroundings.

Furthermore, the data fusion of camera and LiDAR sensors provided a synthetic 3D view of vessels surroundings, which emulates in a VR environment the stereoscopic vision of the human eye, through suitable superposition of the visual textures from the camera onto the 3D point-cloud from the LiDAR (see Figs 2a,b,c from [2]).



**Figure 2a.** LiDAR bow view.

**Figure 2b.** “Stitched” image

**Figure 2c.** Resulting 3D virtual view.

### 2.1.2. The tethered-UAV extended sensor

For the present study, the purpose of the tethered-UAV is to act as an extended sensor of the demonstrator vessel in quality of a visual-based ARPA system (see section 3 of present paper).

The system utilized for this purpose is a DJI Matrice 600 Pro drone, equipped with an orientable downward looking dual optical sensor (visible light / infra-red), and an Elistair SAFE-T 2 tethered module (see Fig 3).



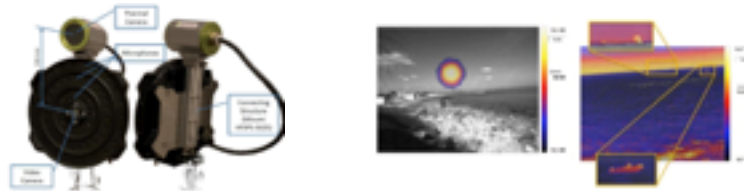
**Figure 3.** Tethered-UVA system onboard of MARIN-UMS demonstrator.

### 2.1.3. The thermal-acoustic surveillance system

The thermo-acoustic surveillance system consists of the following main component:

- Hybrid sensor, which acquires the relevant environmental data
- Data processing unit, which elaborates the data received from the sensor and performs the target detection and identification system
- MMI, which interacts with the Remote Operator allowing control of the system and display of the relevant information

The hybrid sensor integrates a microphone array for passive acoustic target detection of motor-driven vehicles (such as aerial drones or motor boats) and an IR camera to support the Remote Operator in the identification of the acoustic targets and in the detection of silent targets even in total dark conditions (see Figs 4a,b).



**Figure 4a.** Thermo-Acoustic surveillance system. **Figure 4b.** Thermos-acoustic identification.

## 2.2. Ship-Shore Communication system

As the intended deployment of the demonstrator vessel was in close coastal water, for the present study we focused attention on LOS broadband radio communications. More specifically, we selected the following communication technologies:

- 4G LTE mobile network (as 5G was not available at the testing site)
- Super HF broad-band radio

### 2.3. Remote Control Center

The purpose of the RCC was to provide the Remote Operator with a control and monitoring capability for auto-remote operations of the demonstrator vessel. Its main components were the following:

- Portable Control Station (PCS)
- PC workstation
- Network switch

The PCS allows interactive control of navigation functions (see Figs 5a,b).



Figure 5a. Virtual Operator Panel for DP functions.



Figure 5b. GUI of ECDIS control.

### 3. Provide Situational Awareness to Remote Operator

As far as the ship-side component of SA system is concerned, Artificial Intelligence (AI) allows to utilize the streaming from external-looking cameras mounted onboard own ship for automatic detection of surrounding vessels thus actually transforming the cameras into a Video Object Detection System (VODS).

In the present study, a prototype VODS has been implemented, based on the application of the most recent Deep Learning techniques (YOLOv4) to the images of the video 360° system; a Convolution Neural Network (CNN) was trained with a large number of RGB images of marine scenarios and was able to detect and label a "boat" object within a complex maritime context (see Fig 6a from [3]).



Figure 6a. YOLOv4 object detection results for a typical maritime scenario.

The effectiveness of VODS as a COLAV-aid is however impaired by the 2D nature of the images. Even if this issue could be in principle solved through the correlation of video and LiDAR data, for the present study a different approach has been investigated, which consists in applying the same video detection techniques to the aerial images taken from the downward-looking camera of the tethered UAV system: this way the drone could be utilized as a sort of visual-based ARPA system.

In the following Fig 6b, some preliminary results are shown for the application of this methodology to aerial data in a maritime context [2].

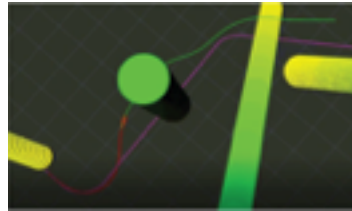


**Figure 6b.** Examples of YOLOv4 object detection results for aerial maritime images.

#### 4. Provide Collision Avoidance Advisory and Control

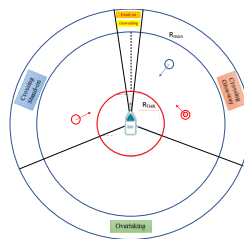
The reactive COLAV Auto-Pilot studies in MARIN Project assumes that the ship is following a given route, initially free of obstacles, and that along its course the onboard sensors perceive the risk of collision with one or more incoming vessels.

A *protocol-free COLAV* algorithm was developed to locally modify the route in order to avoid the foreseen collision events, without the requirement of compliance with the relevant COLREGs rules. For the present study, a variant of the so-called “timed elastic band” algorithm was applied [4], able to find in real-time the shortest route between two points which is free of immediate collision risks and can be mathematically described as a Dubins path. This approach was extensively tested in a simulation environment according to HIL testing methodology [5], with the COLAV algorithm running on a PC and the COLAV Auto-Pilot running on its intended deployment hardware (i.e. an industrial PLC); mathematical model of ship maneuvering was further implemented on the PC using MATLAB / Simulink (see Fig 7 below).



**Figure 7.** Example of HIL simulations for Reactive COLAV AP.

A *protocol-based COLAV* algorithm was further developed to assist navigation in open international waters, subjected to compliance with COLREGS Rules [6], based on the information from the *Sensor Fusion* of standard AIS / ARPA equipment. The system shall visually support the OOW on COLAV decision-making through the following four-quadrant situational diagram (see Fig 8 below):



**Figure 8.** COLAV four-quadrant situational diagram.

## 5. Preliminary at-sea tests for Auto-Remote operations of MARIN-UMS

The quay for the Auto-Remote operations of the MARIN-UMS was set up at the secondary headquarters of the Tringali Shipyard at Punta Cugno. The test area, located in the Augusta bay in front of the ESSO area, was chosen based on considerations of visibility from the site of the Shipyard, where the RCS is located, and LOS coverage of communications MBR/4G.

During sea-trial the following tests were conducted from the RCC (see Fig 10):

- Remote manual control of the actuators.
- Remote Semi-Automatic (Joystick) and Automatic (DP) Mode.
- Remote Autopilot - Heading Control / Track Control / Speed Control



Figure 10. Auto-Remote operations Main Views.

## 6. Conclusions

In this last half decade, there has been a significant surge of interest towards the topic of Maritime Autonomous Surface Ship (MASS) from all the maritime stakeholders. The increasing role of automation systems in the conduction of the ship and the corresponding progress in sensing technologies and AI algorithms from other fields (such as robotics and automotive), make MASS a feasible concept in the near future. For a fully-operational implementation of this concept, there are however a series of issues to be addressed and solved, not only from the purely technological point of view, but in terms of operational effectiveness and reliability.

MARIN project mainly focused on the problem of providing E-SA and Decision Support to the Remote Operator, respectively for collision detection and avoidance, addressing in particular:

- Innovative control system for auto-remote navigation, blending DP and AP type algorithms to provide control over the whole speed range.
- Enhanced Environmental Perception, through a combination video / LiDAR 360°, EO and radar.
- Enhanced Operational Understanding, through application of DL techniques for automatic object detection and AR techniques for visually correlating video images and navigation data.
- COLAV Auto-Pilot, using AI techniques for protocol-free COLAV and Expert System type approach for COLREGs-compliant COLAV.

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## References

- [1] DNV GL. Autonomous and remotely operated ships. DNVGL-CG-0264 Class Guideline. 2018.
- [2] Mancarella L, Calabrese F, Cataldo M, Serafino G, Paiano L, Carlino L, Cirigliano A, Leonardi N, Sansebastiano E, Sebastiani L. A novel integrated multi-system approach for situational awareness in maritime environment. Paper accepted for COMPIT 2022 International Conference; 2022 Jun 23-26; Pontignano (IT).
- [3] Faggioni N, Leonardi N, Ponzini F, Sebastiani L, Martelli M. Obstacle detection in Real and Synthetic Harbour Scenarios. Proceedings of MEAS 2021 International Conference; 2021 Oct 13-14; Virtual Edition.
- [4] Tornese R, Polimeno E, Pascarelli C, Buccoliero S, Carlino L, Sansebastiano E, Sebastiani L. ROS-based simulation environment for obstacle avoidance in autonomous navigation. Paper accepted for CCTA 2022 International Conference; 2022 Aug 22-25; Trieste (IT).
- [5] Tornese R, Polimeno E, Pascarelli C, Buccoliero S, Carlino L, Sansebastiano E, Sebastiani L. Hardware-in-the-loop testing of a maritime autonomous collision avoidance system. Paper accepted for MED 2022 International Conference; 2022 Jun 28 – Jul 1; Athens (GR).
- [6] IMO. COLREGs—International Regulations for Preventing Collisions at Sea. 1972.