MARINE AIDS TO NAVIGATION IN A CHANGING ENVIRONMENT

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# Use of UAV for the Performance Assessment of Visual Aids to Navigation

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SUMMARY

Coastal and inshore navigational areas are becoming increasingly congested not only due to the vessels traffic, but also from the more recent economic activities such as offshore wind farms, tidal turbines and aquaculture sites. At the same time the challenges presented by coastal development like "light pollution" or operational requirements of larger vessels or high-speed crafts are imposing more complex design solutions for the Aids to Navigation (AtoN). On the other side, users are calling for higher effectiveness of the service being provided, namely through clear statements of the level of service and performance standard. Over the last decade we have witnessed a large diversity of UAV application solution in several domains. The associated technology is becoming cheaper, easily achievable and with higher levels of performance. This paper presents the results of several tests to validate the conceptual use of UAVs in the performance assessment of AtoN. Results point to the possibility for the definition of more detailed performance indicators of AtoN. UAVs fitted with optical sensors may simulate the perception of observers at several heights and directions. Above all, they provide a systematic methodology to assess or monitor the conspicuity of AtoN at pre-set positions or paths.

*RESUME*

*Les zones de navigation côtières ou intérieures sont de plus en plus congestionnées, non seulement en raison du trafic maritime mais aussi à cause d'activités économiques récentes comme les champs d'éoliennes, les hydroliennes et les fermes aquacoles. Dans le même temps, les défis posés par le développement côtier comme la «pollution lumineuse» ou les exigences opérationnelles des grands navires ou des navires à grande vitesse imposent des solutions de conception plus complexes pour les aides à la navigation. En face, les utilisateurs réclament une plus grande efficacité du service fourni, à savoir par des déclarations claires sur le niveau de service et la norme de performance. Au cours de la dernière décennie, nous avons assisté à une grande diversité de solutions d'application d'engins aériens sans pilote dans plusieurs domaines. La technologie associée devient moins chère, facilement réalisable et avec des niveaux de performance plus élevés. Cet article présente les résultats de plusieurs tests visant à valider l'utilisation conceptuelle des engins aériens sans pilote dans l'évaluation de la performance des aides à la navigation. Les résultats indiquent la possibilité de définir des indicateurs de performance plus détaillés pour les aides à la navigation. Les drones équipés de capteurs optiques peuvent simuler la perception d'observateurs à plusieurs hauteurs et directions. Surtout, ils fournissent une méthodologie systématique pour évaluer ou surveiller la visibilité d'une aide à la navigation à des positions ou des chemins prédéfinis.*

# CONTENTS

# 1. INTRODUCTION

Coastal and inshore navigational areas are becoming increasingly congested not only due to the vessels traffic, but also from the more recent economic activities such as offshore wind farms, tidal turbines and aquaculture sites. At the same time the challenges presented by coastal development like "light pollution" or operational requirements of larger vessels or high-speed crafts are imposing more complex design solutions for the Aids to Navigation (AtoN). For the next 20 years, large growth in seaborn trade is projected, followed by an increase of about 2 times in ships sizes [1]. Offshore renewable energy resources will have a key part in the strategies for sustainable carbon reduction and the number of devices (offshore winds, wave, tidal and ocean current energy) are expected to increase between hundreds and thousands of times, until 2030 [1].

Despite the important role of technology in improving safety and efficiency, we still need to recognize and address its limitations [2], namely new forms that comes alongside with the digitalization trend. Some examples are the increased complexity [3] derived from interconnected subsystems, interactions of many control parameters and indirect information sources [4], [5]. Cybersecurity is also an increasing matter of concern [4], already being tackled by IMO [6] and by IALA in the Maritime Cloud Initiative.

On the other side, users are calling for higher effectiveness of the service being provided, namely through clear statements of the level of service and performance standard. Considering the principles proposed by [7] for High Reliability Organization (HRO), along with the preoccupation with failures, we must be sensitive to the operations and committed to resilience. Supporting resilient operations requires anticipating events and monitoring the systems [8]. Getting continuous feedbacks over the performance of visual AtoN from the end-users is still a challenging task, despite the multiple initiatives made.

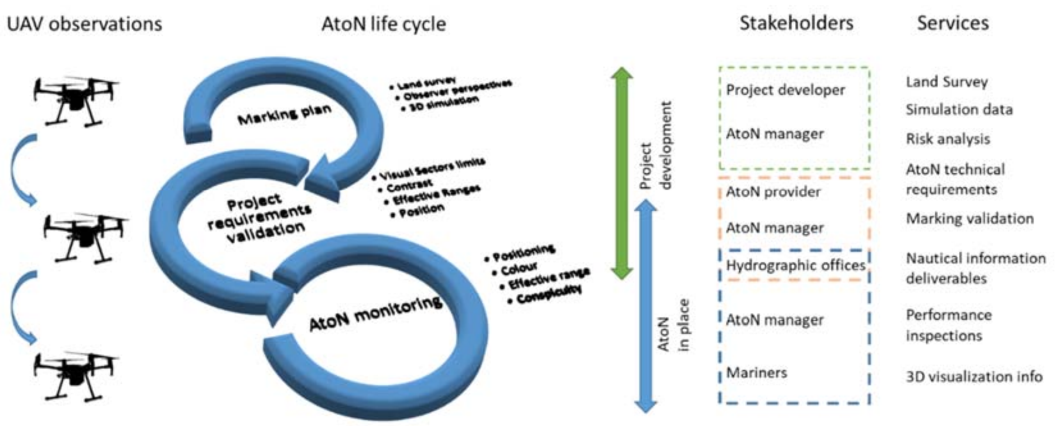
Unmanned Air Vehicles (UAV) brought the possibly of new solutions to tackled daily problems found in large number of working domains. Offshore oil and gas industry has already started to employ UAV for inspection services. Pursuing the efficiency of surveying services, in August 2017, DNV GL performed its first survey on an offshore unit [9] and is working on the development of for UAV-based inspection procedures.

To address the need for enhanced performance assessment of visual AtoN, we propose the development of an UAV-based systematic survey. UAV are fitted with a set of sensors, mostly electro optics, which combined with positioning and navigation systems and large band data links, provides a significant enhancement of present monitoring capabilities. The undergoing study, started in November 2017, is jointly undertaken by the Portuguese Lighthouse Authority and the Hydrographic Institute, with the Naval Research Centre (CINAV) and an UAV provider for innovative solution (ISkyex). Trials have been made in Portuguese ports and the currently stage is focused on developing and validating the UAV technical requirements.

As work evolves, more expected outcomes are identified among those originally set. It enables increased number of surveys and inspections, gathering digital data in a systematic way. This information can them be also used to update published nautical information, or present information in innovative ways. The same methodology can be used to collect information required for marking plans e and risk analysis. Finally, after establishing systematic survey procedures, this can be used to develop a new framework for the assessment of AtoN with digital indicators. UAV observations also facilitates data collection of AtoN located in places of difficult access. Additionally, it may be used to assess and validate the performance of new AtoN, simulating different navigators profiles (elevation and speed).

Despite all the foreseen advantages, we must acknowledge new types of obstacles, such as UAV endurance in sea environment, floating capability in case of failure, and legal constraints to UAV operations.

***Image 1 – UAV applications at different stages of AtoN life cycle***




## 2. SERVICE LEVEL

IALA Guideline 1004 [10] provides information on how to develop an appropriate level of service and how to calculate Availability. Level of Service corresponds to a bilateral agreement between the competent Authority(ies) and mariners or other clients who are operating in a navigational area. These agreements are tailor-made to suit the navigational safety requirements, and they entail the provision of information by users to the providers to assess the fulfilment of the agreed levels.

The purpose of Service levels is to inform the users of the waterway of the aids they may expect and use, and to facilitate the control of the performance of the provided services. To achieve that, users and providers should mutually agree benchmarked service levels. While setting this service levels, participants must ponder over the reasonability, prioritization and monitoring capability of the agreed indicators [11].

IALA [10] suggest that the development or review of service levels should involve the assessment and considerations of all interested stakeholders. Therefore, the competent authorities must put in place procedures for monitoring the performance of the services.

Risk assessment, in design of marking plans, is one of the key elements in rule 13, chapter V of the SOLAS Convention, and is a mechanism that IALA largely recommends setting the appropriate type, extent and quality of services. The established performance standards must be controlled and properly monitored based on various factors [12]. One of those is related with the availability and effectiveness of the visual aids to navigation regarding the agreed levels of services and envisaged operational and environment conditions.

An essential element of service level frameworks, is the ability to or the following parameters:

• Assess performance criteria and levels;

• Monitor performance indicators;

• Monitor and revise survey procedures;

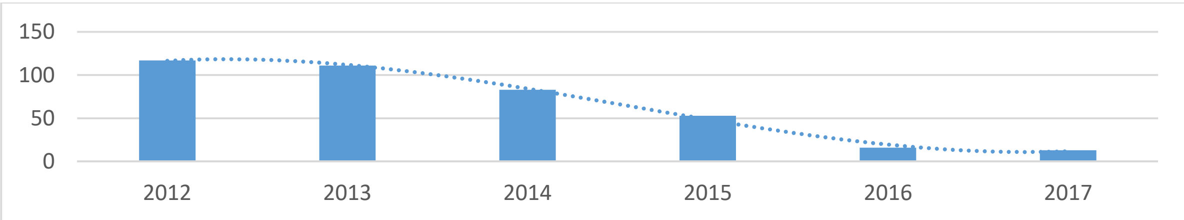
## 3. ATON PERFORMANCE ASSESSEMENT

To surround the difficulty in getting information from the mariners, the Portuguese Navy cooperates with the Portuguese Lighthouse Authority in the evaluation of the conspicuity and range of the visual AtoN, since the late 80´s. This cooperation is reached with the request for naval ships to provide a report anytime a visual AtoN is sighted. This formatted report, named "FARCOM" contains the following information:

- Name and list of lights number;
- Maximum observed range / nominal range / sector and bearing / day or night;
- Observation time;
- Meteorological conditions and visibility in nautical miles;
- Additional observations (conspicuity, background, colour or characteristic, any relevant information …).

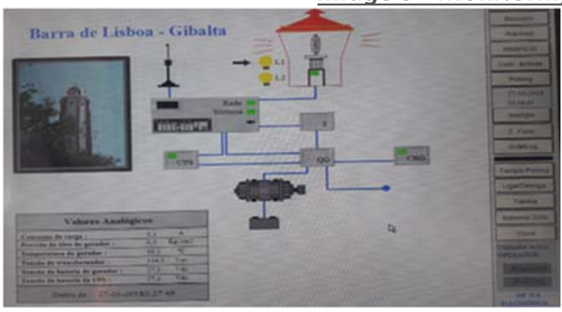
Despite the initial benefits, the effectiveness of this procedure is decreasing, since we are observing a continuous and significant reduction in received reports, as it is shown in the diagram of Image 2. As stated in [13] the involvement of the end users is the monitoring process loop is poor, and when information is received, the integrity and reliability is questionable.

*Image 2 – Number of received FARCOM reports between 2012 and 2017*




The Portuguese Lighthouse Authority operates a remote and automatic monitoring system from the central facilities, in line with the IALA guidelines [13]. However, this system only covers the lighthouses of Lisbon area. Besides the warnings notice, this system logs lights functioning parameters anytime a fault is detected.

*Image 3 - Monitoring system software interface*




The Lighthouse Autority and others AtoN providers, perform periodic inspections. These are mostly related to the technical parameters of AtoN lights and power sources. The technicians identify failures and verify if the AtoN operates within the defined specifications. The information is compiled and record in a form sheet and later assed at office.

From a different perspective, self-assessment systems are one of the mechanism that support the development of a Quality Management System (QMS) [14]. Following the definition of performance criteria, it is necessary to measure and monitor the delivered service.

## 3.1. INFORMATION REQUIREMENTS

A systematic approach was made to set the requirements for information related with AtoN performance. Four categories were identified, even though some information elements might naturally be commonly shared between more than one category. Classification's criteria are based on the function or duty that the observation is used for. The categories are:

a) Marking plan: information and observations required for the development of a marking plan, namely to support the risk assessment [12]. During the project requirements phase, information obtained through this system can be very useful to identify constrains and opportunities in the layout and design of the marking system and of the AtoN itself;

b) AtoN Validation: Observation required to validate the performance of a new visual AtoN, in accordance with the project criteria;

c) AtoN Monitoring: information and observations to assess the performance indicators. It also includes the characterization of changing conditions, such as visual background noise;

d) Nautical Information: digital information related with AtoN to be published in the nautical documents (publications and charts). The data obtained from the monitoring runs of the system will be essential to keep mariners informed of the limitations of the AtoN in place, allowing for the timely promulgation of maritime safety information. Innovative forms of presenting information currently published in coastal sailing directions.

IALA already proposes guidance for the collection of AtoN performance data on failures and reliability [15]. The identified performance indicators are: availability, reliability, continuity, redundancy, integrity, mean time between failures (MTBF) and, mean time to repair (MTTR). The same guideline, considers the need to measure additional performance indicators to support the assessment of the specified or predicted characteristics of equipment with the actual field performance.

# 4. UAV CAPABILITIES

The main parameters that initially identified concerned with the flying performance of the UAV. Different flight control modes used by the UAV operator, considering the possibility of operating the UAV from small vessel. AUV should have enough autonomy to perform a minimum set of observation procedures. Operational range were mostly constrained by remote control modes and real time data stream requirements. Finally, risk analysis had to made for each place, considering for instance the legal framework for UAV operations and weather forecast.

Additionally, a record of the UAV sensors need be made to provide a detailed assessment of the collected data. All UAV used for this study, were prototypes specially designed for this type of operations.

Example of some sensors parameters:

GNSS receiver: ________________
- Horizontal Accuracy (95%): ______________________________________
- Vertical accuracy (95%): ______________________________________

IMU sensor: ________________
- offset error: ______________________________________
- stability performance: ______________________________________
- repeatability: ______________________________________
- scale factor error: ______________________________________
- misalignment error: ______________________________________
- noise: ______________________________________

Calibration methods: ____________________________________________
Gyroscope: ______________
Calibration methods: ____________________________________________
Magnometer: ______________
Calibration methods: ____________________________________________
Barometer: ______________
Vertical error: ________
Calibration methods: ____________________________________________

## 5. METHODOLOGY

Following the analysis of the literature associated with AtoN operational performance, several meetings between the project partner were conducted to establish a workplan and elicitation of some preliminary requirements. The initial work started with the characterization and understanding of UAV technology and operational requirements.

***Image 4 – Schematic description of UAV***

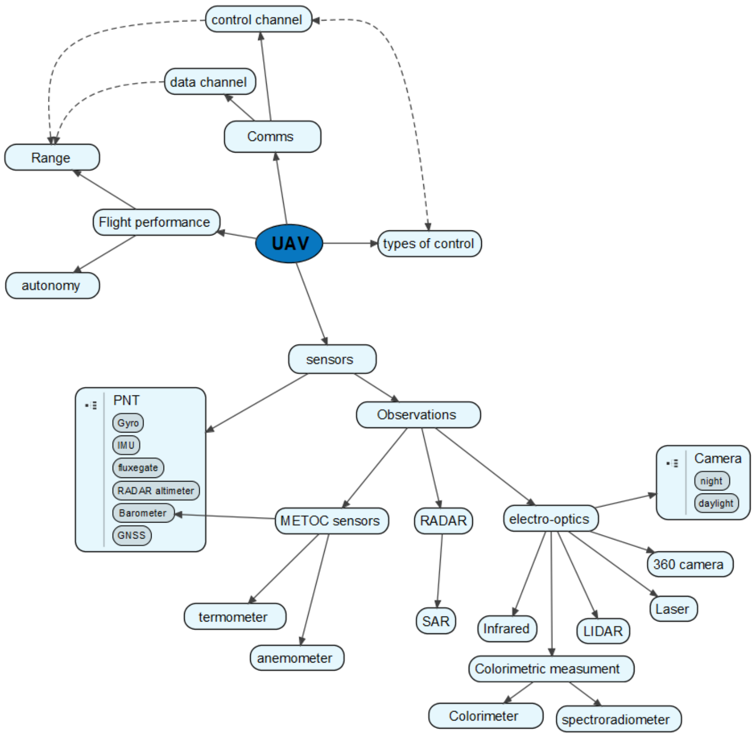
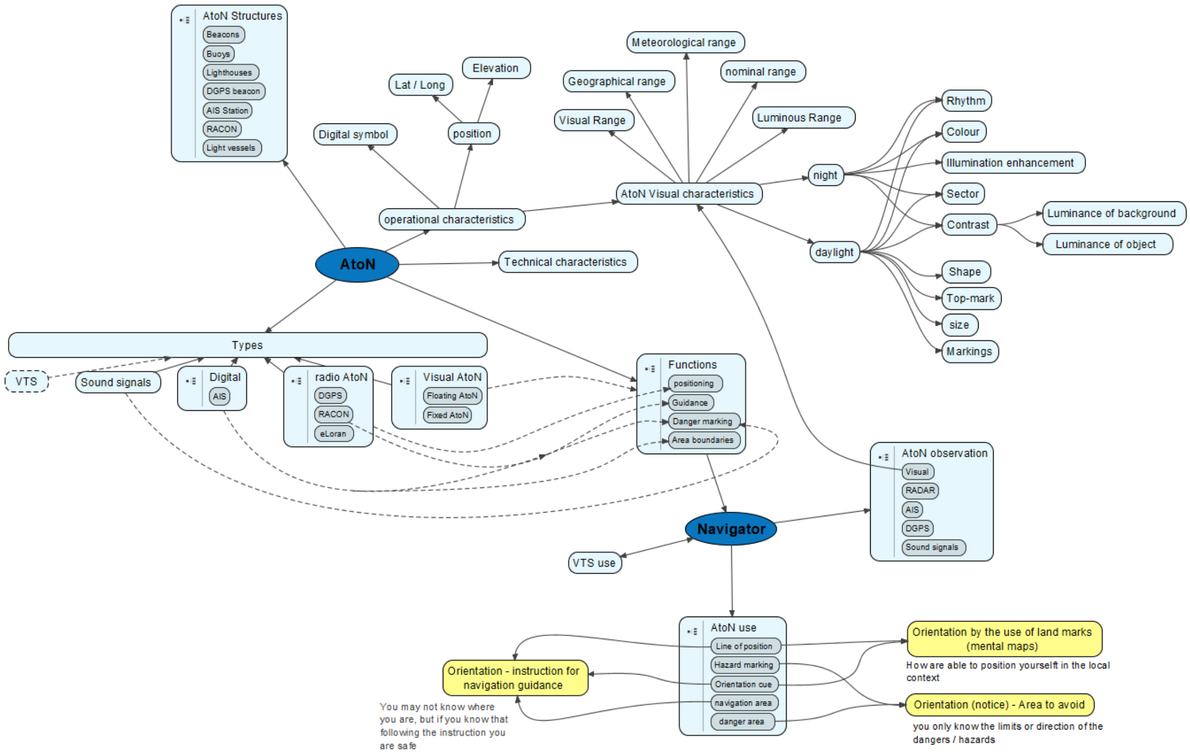


*Image 5 – Schematic representation of the AtoN operational requirements*




A workshop was organized with the main objective of developing the users' requirements, from both AtoN providers' and mariners' perspectives. During this workshop it was possible to define some prototype design requirements, to allow for the development of the first UAV.

Up to the present date, some sea trials were undertaken as an iterative development process, few of them on-board vessels. These trails provided valuable insights over the challenges regarding with the operation of UAV at sea, namely with the need to balance autonomy and range. Several types of cameras were tested to assess image definition and field view. Different UAV control modes and flight plans were also tested to develop a systematic framework of measurements. The adverse weather conditions were dominant during the winter (2017-18) imposing several trail interruptions and postponements. Moreover, legal procedures to operate UAV at higher altitudes and longer distances needs to be submitted with 12 days in advances, being extremely difficult to get reliable weather forecast.

# 6. RESULTS

## 6.1. MATRIX OF MEASUREMENT REQUIREMENTS

From the work developed at the workshop a matrix of different types of measurements was defined, to be used as guidance for the field trials.

| ID | Observation | measurement description | observables | Sensor 1 | Sensor 2 | Sensor 3 | Sensor 4 |
|---|---|---|---|---|---|---|---|
| 1 | AtoN position | UAV vertical | Coordinates (horizontal) | GPS | IMU | EO | |
| 2 | AtoN inspection | EO information on AtoN physical conditions.<br>360ª inspection highest resolution | Painting conditions<br>structural damages<br>corrosion | EO | | | |
| 3 | AtoN daylight conspicuity | EO information in the usable arc of visibility at a specific distance. | Contrast with background position, height and bearing of observations | EO | GPS | IMU | Barometer |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Radius depending on EO camera and distance to background features | | | | | | |
| 4 | AtoN night conspicuity | EO information in the usable arc of visibility at a specific distance.<br>Radius depending on EO camera and distance to background light noise | Contrast with background lights<br>position, height and bearing of observations | EO | GPS | IMU | Barometer |
| 5 | AtoN daylight range | Effective range and detection range<br>Identification range (shape, colour, top mark, numbering).<br>Radial approximation | Detection and identification range | EO | GPS | IMU | Barometer |
| 6 | AtoN night range | Effective range and detection range<br>Identification range (colour, rhythm)<br>Radial approximation | Detection and identification range | EO | GPS | IMU | Barometer |
| 7 | Leading line daylight sensitivity | Effectiveness of leading lines.<br>Path over leading line azimuth at specific elevation IAW operational use (mariners elevation)<br>Leading marks perspective from channel limits<br>Simultaneous observation for AtoN conspicuity and range | Leading line sensitivity<br>Vertical divergence of leading marks<br>Mariners perspective ("street view") over the passage plan | EO | GPS | IMU | Barometer |
| 8 | Leading line night sensitivity | Effectiveness of leading lines.<br>Path over leading line azimuth at specific elevation IAW operational use (mariners elevation)<br>Leading marks perspective from channel limits<br>Simultaneous observation for AtoN conspicuity and range | Leading line sensitivity<br>Vertical divergence of leading marks<br>Mariners perspective ("street view") over the passage plan | EO | GPS | IMU | Barometer |
| 9 | Sector lights limits | Assessment of light sector limits.<br>Circular path at specific distance to AtoN | Sector limits' azimuth | EO | GPS | IMU | Barometer |

*Table 1 - Table of observations and measurement criteria*

## 6.2. DATA COLLECTION

### 6.2.1. PLANNING

Base of operations had to consider the need to control the UAV on sight, with a maximum distance from base of 2000 metres

The next diagram shows an example of the available options for the port entrance channel.

*Image 6 – Available options for base site selection (circle space 1 000m)*

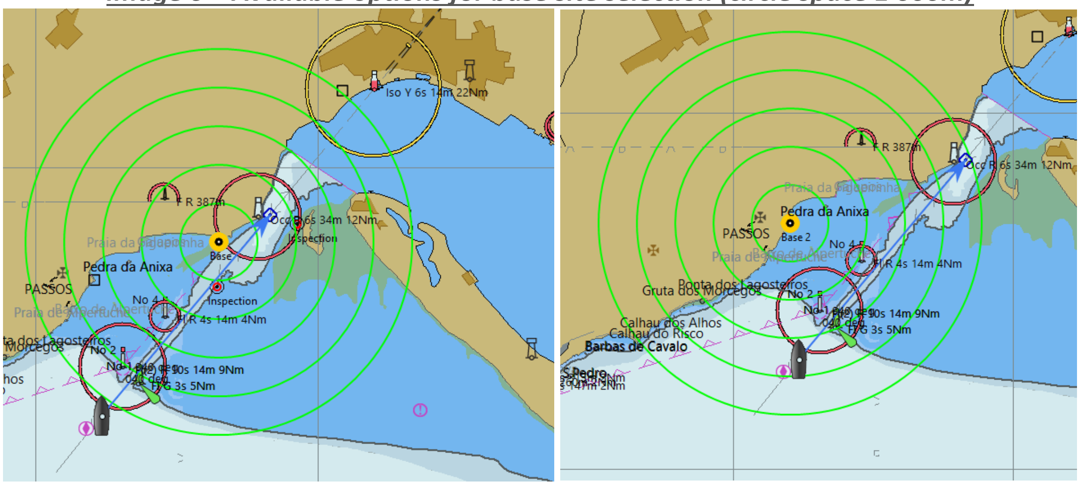
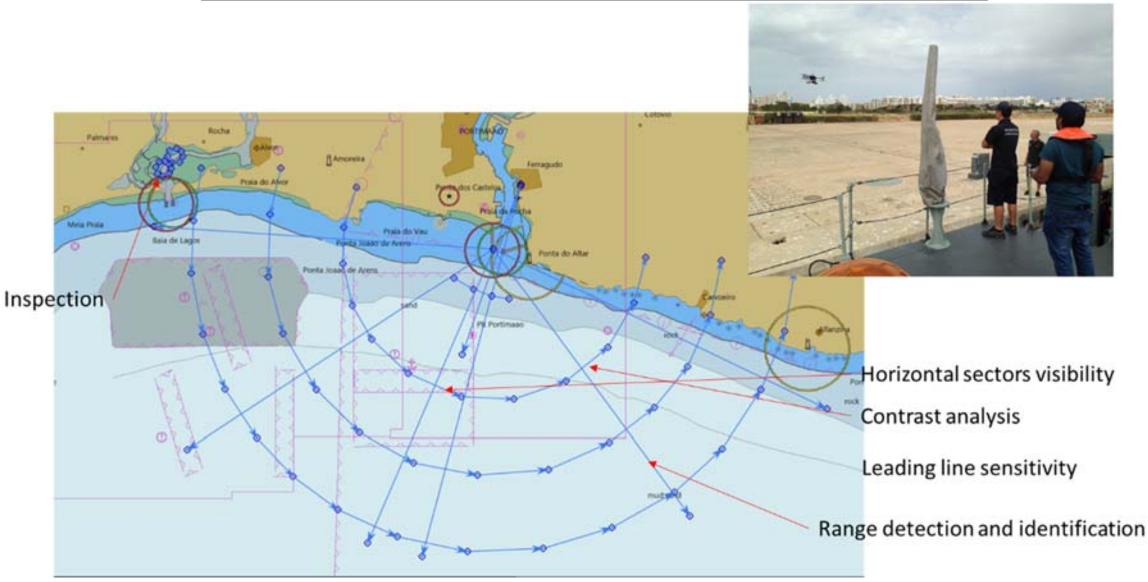


*Image 7 – plan for of the first trials, June 2017 Portimão Harbour*




### 6.2.2. AtoN position

To check the position of floating aids, the UAV is placed hoovering over the AtoN, for 2 to 5 minutes to get an averaging position of the AtoN. Horizontal positioning is made with the help of the EO sensors that is set vertically. Measurement are later averaged to obtain a mean position and checked if its fits within the minimum radius of expected position.

### 6.2.3. AtoN inspection

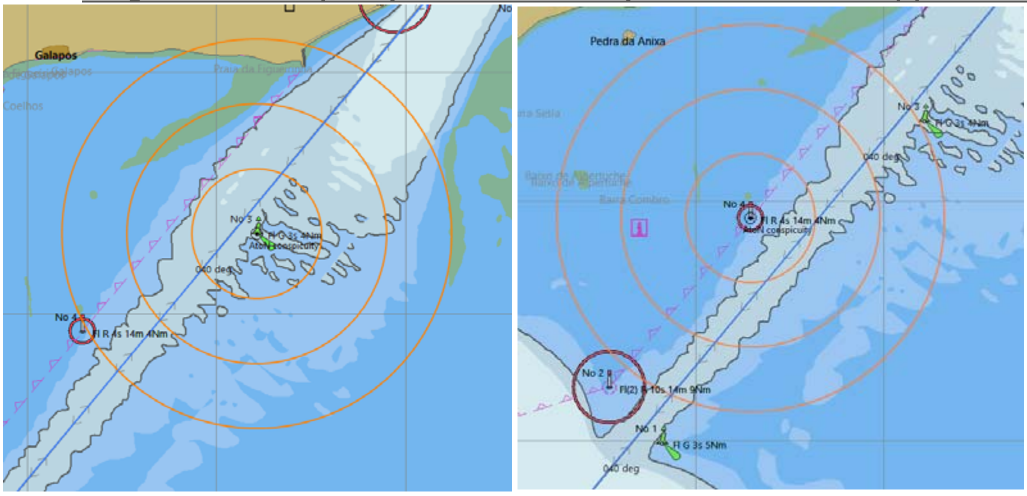
For get information over the AtoN physical state the UAV collects image data on a circular path around the aids, at less than 50 metres, depending on the EO camera quality.

*Image 8 – Inspection of a beacon*

### 6.2.4. AtoN daylight conspicuity

Visual aid conspicuity observation were obtained by performing a circular path around two aids, one beacon and one buoy, at 3 different distances over the usable sectors. The 3 distances were used to provide different sets of image data to support de definition of the most appropriate one, based on the users' calibrations process.

*Image 9 – Aids conspicuity evaluation at buoy nr3 and beacon nr 4 (space circle 500 m)*

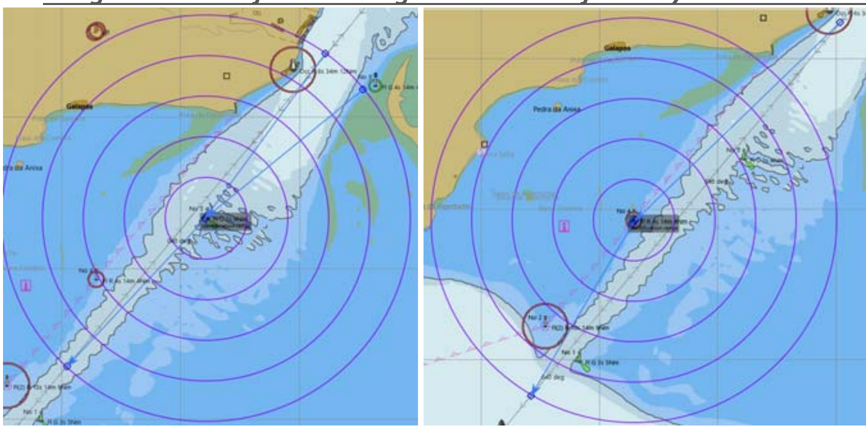



### 6.2.5. AtoN daylight range

Daylight range evaluation was performed with the execution of several radial paths to and from the aids. During Setúbal trials one buoy and one beacon were used, as shown in the next images.

*Image 10 – Approaches to beacon for Daylight range evaluation*

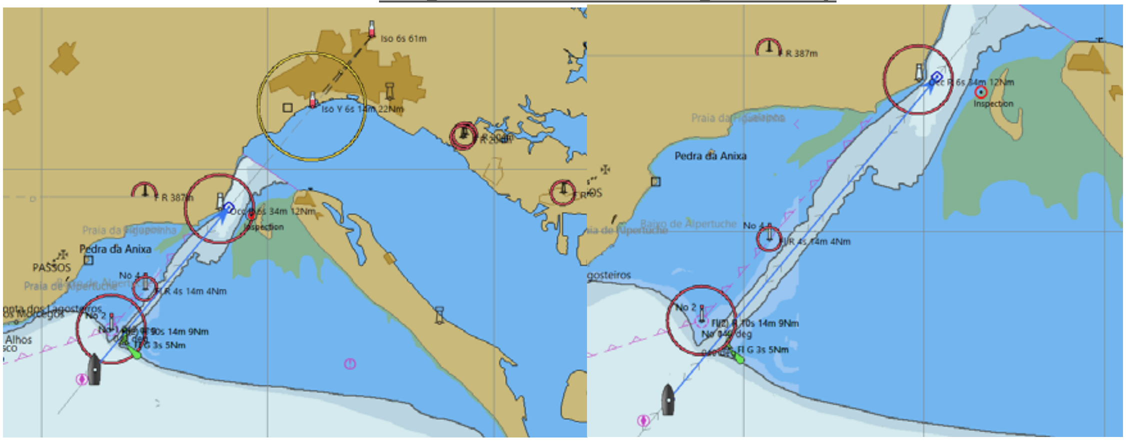
*Image 11 – Identification range observation for buoy nr 3 and beacon nr4 (circle space 500m)*



### 6.2.6. Leading line daylight sensitivity

Observation made over the leading line are achieve through the execution of a flight path at different altitudes representing the most common observer heights found on the area. For the second trial, located at Setúbal harbour, 3 heights were set (3, 15 and 30 metres) reflecting 3 groups of mariner’s observer elevation levels typical of the area.

*Image 12 – Setúbal Leading line entry*




## 7. CONCLUSIONS

From these preliminary results we could identify some limitations and challenges that need to be addressed in the upcoming work, namely related with:

- UAV autonomy and above water operational requirements;
- UAV Sensors calibrations;
- Calibration matrix of Electro optics versus human eye (mariner perspective);
- The need of special training required by UAV operators;
- Safety and regulatory constraint to operate UAV and collect image data;
- Additional constraints for night time operations and measurements;

On the other hand, we may foresee some advantages of the use of UAV to measure AtoN's performance, such as:

- Systematisation of measurements supports the development of an objective performance benchmarking;
- Once a flight path is validated for measurement, it can easily be repeated, reducing bias while comparing different sets of observations;
- Sensors can be calibrated to standards matrix of classification, which is quite problematic to define for the human eye in real scenes.
- Performance indicators may be provided with greater accuracy;
- The digitalization of data collection, allows for:
    - Multiple use of same observation (AtoN manager and Hydrographic office)
    - In depth analysis of data, for instance enhance capability for comparison with previous observations.
    - Reduced operational cost with increased number of surveys / inspections.
- There is no need for boats and it facilitates the access to remote places, where some AtoN are found.
- Not dependent on sea state, wind force limit at around 20 knots, depending on selected UAV.

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